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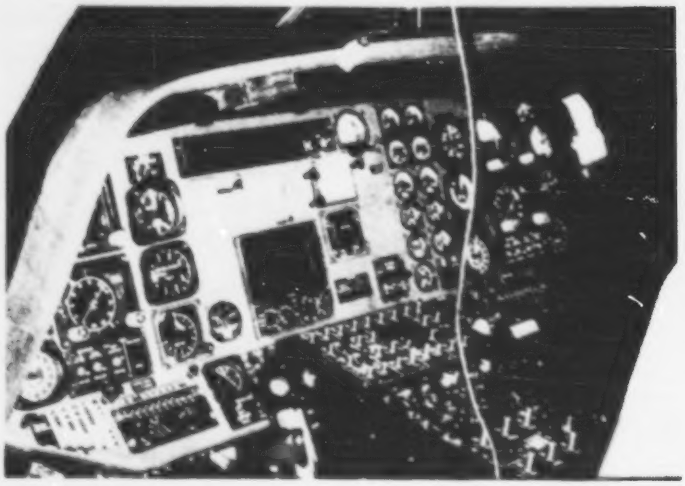
Light Bulb Filament Impact Dynamics Study

in support of Aircraft Accident Investigation



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Light Bulb Filament Impact Dynamics Study

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17. Abstract

A study conducted during the period August 1982 to October 1984 to investigate the behaviour of aircraft light bulbs at impact is reported. The study largely consisted of laboratory impact testing of over 400 General Electric type 327 miniature light bulbs that are typically used in order to correlate the type of damage exhibited by the tungsten filament to the state of the light bulb at impact (i.e.: on or off). The impact tests were instrumented to provide acceleration-time data in order to relate severity and type of impact to filament damage. Analysis of light bulbs can be a valuable tool for aircraft accident investigators as many aircraft contain numerous light bulbs to illuminate various caution, warning, and system failure indicators.

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17. Résumé

Ce rapport rend compte des études faites entre août 1982 et octobre 1984 sur le comportement des filaments d'ampoules au moment de l'écrasement d'un avion. La recherche, qui a surtout consisté à essayer sous impact plus de 400 ampoules General Electric 327 largement utilisées dans les tableaux de bord, visait à établir la corrélation entre la forme de rupture du filament de tungstène et l'état où se trouvait l'ampoule (allumée ou éteinte) au moment de l'impact. Les essais avaient été instrumentés de manière à fournir des courbes accélération-temps mettant en évidence le rapport entre les impacts de nature et d'intensité variables et la forme de rupture. L'analyse dynamique des filaments d'ampoules peut constituer un outil de recherche très intéressant pour les enquêteurs, du fait que le tableau de bord des avions comporte un grand nombre d'ampoules servant de témoin: alerte, avertissement, indication d'état, etc.

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LIST OF SYMBOLS

g = ratio of acceleration to 9.81 m/s^2

Hz = Hertz

KE = Kinetic Energy (newton-meters)

m = mass (kilogram)

PE = Potential Energy (newton-meters)

R = Resistance (ohms)

t = time (seconds)

T.E. = Total Energy (newton-meters)

v = velocity (meters per second)

V = voltage

V_d = design voltage

V_a = applied voltage

SUMMARY

For many years the analysis of damaged light bulbs has been an important tool used by aircraft investigators to infer the operating condition of various aircraft systems at the moment of impact; this has been especially valuable for systems associated with failure warning lights.

Prior to the research described in this report, the only known work on aviation light bulb impact analysis was that published in 1966 by the R.C.A.F. and used throughout the world for nearly two decades. The present work is based on more advanced investigation techniques and more sophisticated impact testing equipment.

The work concentrates on the 327 type bulb, which is widely used as an indicator and warning bulb in many types of civil and military aircraft throughout the world.

The initial phase of the experimental work was devoted to setting up and calibrating the numerous items of test equipment and to determining the optimal bulb alignment for clearest results. The main test phase consisted of drop-testing hundreds of bulbs under varying conditions of:

applied voltage
aging under controlled vibration
magnitude of impact
duration of impact

Supplementary phases explored such factors as old age, excessive voltage, resonance and illumination times.

A scanning electron microscope was used extensively to examine the filaments and to photograph them. The results were analyzed and conclusions drawn. The latter affirm that it is possible, using strict investigative procedures, to establish the condition of a warning system circuit ("ON" or "OFF") at the time of impact by examining the relevant light bulb in conjunction with the information published in this report.

To facilitate investigation in the field, "A Guide to Light Bulb Analysis in Support of Aircraft Accident Investigation", TP 6255E, has been published and widely distributed in Canada and other countries.

SOMMAIRE

Depuis longtemps, les enquêteurs sur les accidents d'avion utilisent la méthode dite du "filament d'ampoule" dont l'analyse permet de déduire l'état où se trouvait un circuit électrique donné au moment de l'écrasement, notamment dans le cas d'un panneau comportant des voyants d'avertissement.

Le seul ouvrage faisant autorité dans ce domaine a été, jusqu'à la parution du Guide dont il est rendu compte ici, le manuel publié en 1966 par l'Aviation royale du Canada et qui a été largement utilisé dans le monde entier au cours des deux dernières décennies. Le présent Guide se fonde sur des méthodes de recherche plus avancées et des essais réalisés sur un matériel plus sophistiqué.

La recherche s'est concentrée surtout sur l'ampoule du type 327, celle-ci se trouvant dans plusieurs types de planches de bord équipant des avions tant militaires que civils, un peu partout dans le monde.

Les expérimentations ont commencé par la mise en place et l'étalonnage des divers instruments de mesure et la détermination de l'emplacement des ampoules sur l'appareillage susceptible de donner les résultats les plus significatifs. Elles se sont poursuivies par des essais de chocs auxquels ont été soumises des centaines d'ampoules dans des conditions variables de:

- tension appliquée,
- vieillissement à des niveaux vibratoires contrôlés,
- choc (intensité et durée).

D'autres recherches complémentaires ont approfondi l'effet de certains facteurs comme l'âge, les surtensions, la résonance et les temps de montée à incandescence.

Les filaments ont été examinés et photographiés sous un microscope électronique à balayage. Puis, les résultats ont été analysés et des conclusions tirées; notamment que, en respectant un mode opératoire des plus stricts, il est possible de déterminer l'état d'un circuit d'avertissement donné ("Marche" ou "Arrêt") au moment de l'écrasement, par l'observation de l'état physique des filaments et en se guidant sur l'information contenue dans le présent rapport.

Ce guide, intitulé "Analyse des filaments d'ampoule - aide à la recherche sur les accidents d'avion", TP 6255F a été publié et largement distribué au Canada et à l'étranger, afin d'aider aux recherches sur les lieux d'un accident.

1.0 INTRODUCTION

1.1 With the development of increasingly complex aircraft and aircraft systems, the accident investigator has become more and more dependent on sophisticated analysis techniques to determine causal factors of an aircraft accident. Consistent with this logical trend, accident investigation has been forced to develop a diversified specialist team approach. A single investigator can no longer acquire all the necessary knowledge for a complete and thorough investigation. Accident investigation normally covers the following major categories:

1) Structures
2) Power Plants
3) Systems
4) CVR/FDR
5) Records
6) Human Factors
7) Operations
8) Witnesses
9) Airtraffic Control
10) Weather

Pre-impact Parameter Analysis, as a part of the investigative process in which the analyst attempts to determine the aircraft and associated systems configuration prior to impact. Under the systems category, pre-impact parameter analysis consists of:

1) Light Bulb Analysis
2) Instrument Analysis

1.2 The analysis of damaged light bulbs is a tool that can be used to infer the states of various systems at the moment of impact. This analysis is especially valuable for systems associated with failure warning lights. Since the state of aircraft light bulbs ("on" or "off") prior to impact, often yields valuable information regarding the pre-crash electrical, mechanical and operational status of the aircraft, it is most important that light bulb analysis be performed as early as possible in the course of an investigation. This can save valuable time and facilitate early development of the accident scenario. In order to determine a light bulb's state at impact, a research study had been initiated by the Aviation Safety Engineering Branch (ASE) of the Canadian Aviation Safety Board and largely funded and managed by the Transportation Development Centre (TDC) of Transport Canada.

1.3 A number of papers have been written on the subject of automotive headlight damage with respect to crash impacts; however, few similarities exist between automotive headlights and aircraft instrument panel lights. A mid-study progress report on this project was presented at the 1983 International Society of Air Safety Investigators Conference. The only known paper prior to this study on the subject of aviation light bulb impact analysis was published in 1966 by the Royal Canadian Air Force. The objective of this study is to create a manual for light bulb impact analysis in light of modern technology. It is expected that this manual would be incorporated into the accident investigation manual of the International Civil Aviation Organization.

1.4 Since the introduction of tungsten as a filament material about 75 years ago, many different types of light bulbs have been developed utilizing an incandescent filament as a source of illumination. Technological advances enabled the manufacture of light bulbs in a variety of sizes to accommodate a growing number of applications, resulting in increased usage in aircraft environments (see Figure 1). Light bulbs in aviation applications can be categorized by their function as follows:

a) indication
b) warning
c) spatial illumination
d) local illumination
e) signal beacon

Although there are many different types of bulbs used in aircraft today, annunciator panels and caution and warning indicators frequently employ type 327 miniature light bulbs. There are several manufacturers of the 327 light bulb such as Chicago Miniature, Stanley and Carley Lamps, but General Electric was found to be the most widely used manufacturer. The 313 type bulb is also very common, but is used mostly as a local illumination light, mainly for instruments and cabin lighting. A search through the "Standard Aero" Catalogue revealed the following list of bulbs in order of most replacements:

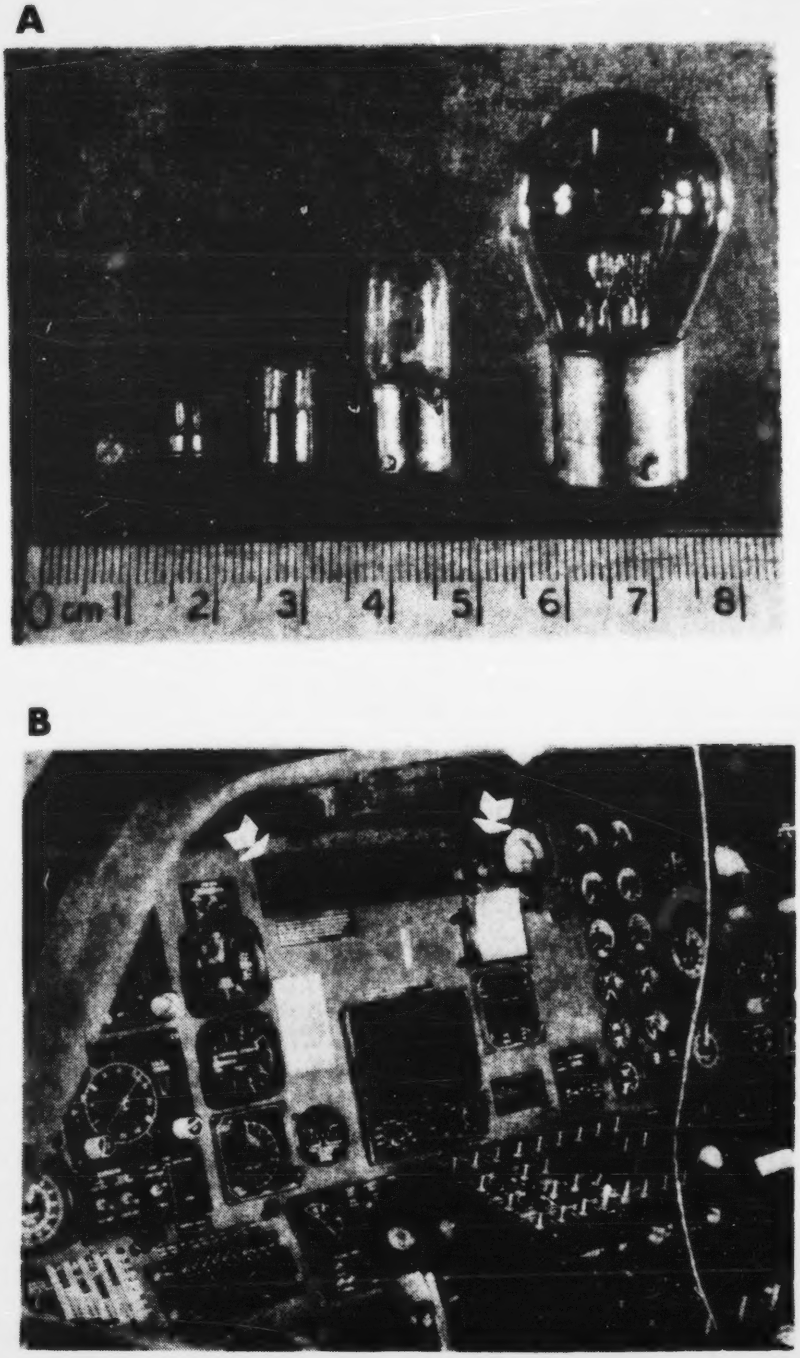


FIGURE 1 - A) ASSORTMENT OF LIGHT BULBS: FROM LEFT TO RIGHT: AIRCRAFT PANEL ILLUMINATION, AIRCRAFT INDICATOR (GENERAL INSTRUMENT 6839), AIRCRAFT INDICATOR (GE-327), AIRCRAFT ILLUMINATION (GE-313), AUTOMOTIVE TAIL LIGHT
B) COCKPIT OF A SIKORSKY HELICOPTER. ARROWS SHOW ANNUNCIATOR PANEL CONTAINING TYPE 327 LIGHT BULBS.

313, 327, 330, 335, 336, 387, 1816, and 1820. Since aircraft accident investigators are most interested in the pre-impact status of indication and warning lights, test equipment and fixtures were made to accommodate the 327 type bulb, and the main test program for this study consisted of impact testing over 400 GE-327 light bulbs. A typical annunciator panel containing type 327 bulbs is shown in Figure 2. This particular panel was retrieved from a Cessna Citation that crashed in a near vertical attitude into a swamp and was totally destroyed, leaving behind no survivors (See Appendix C). Many such panels provide space for more than one bulb to illuminate each indication, which yields increased reliability in determining whether or not the indicator was on or off at the time of impact.

1.5 Figure 3a illustrates a GE-327 light bulb with the elements of the bulb identified as follows:

"A"	Base
"B"	Glass Envelope
"C"	Contact Posts
"D"	Support Posts
"E"	Mounting Bead
"F"	Tungsten Filament

Virtually all aircraft light bulbs contain a very small coiled tunsten filament which is rather difficult to observe in any detail below 30x magnification. The scanning electron microscope (SEM) has become an important analytical tool for the examination of miniature aircraft lights because of its capabilities for examination of objects over a very wide range of magnification (X20 to 20,000) with extremely good depth of field. Figure 3b is a SEM image which illustrates the coiled tungsten filament as it passes through its two support posts. The coiled filament allows for a greater surface area to be confined within a given volume and hence provides greater light output. These coiled filaments typically operate in a vacuum environment, as opposed to a gas environment such as that found in some automotive headlights. The industry uses the indentification letters C-2F to describe the arrangement of the filament and supports for the type 327 and 313 light bulbs, where "C" stands for a coiled filament and 2F indicates the physical configuration on the support. Since each type of light bulb may have a different arrangement of internal components, the type of bulb becomes an important factor in light bulb analysis. For example, some smaller lights contain a shorter, coiled-coil filament which typically is able to endure larger impacts without exhibiting damage. As well,

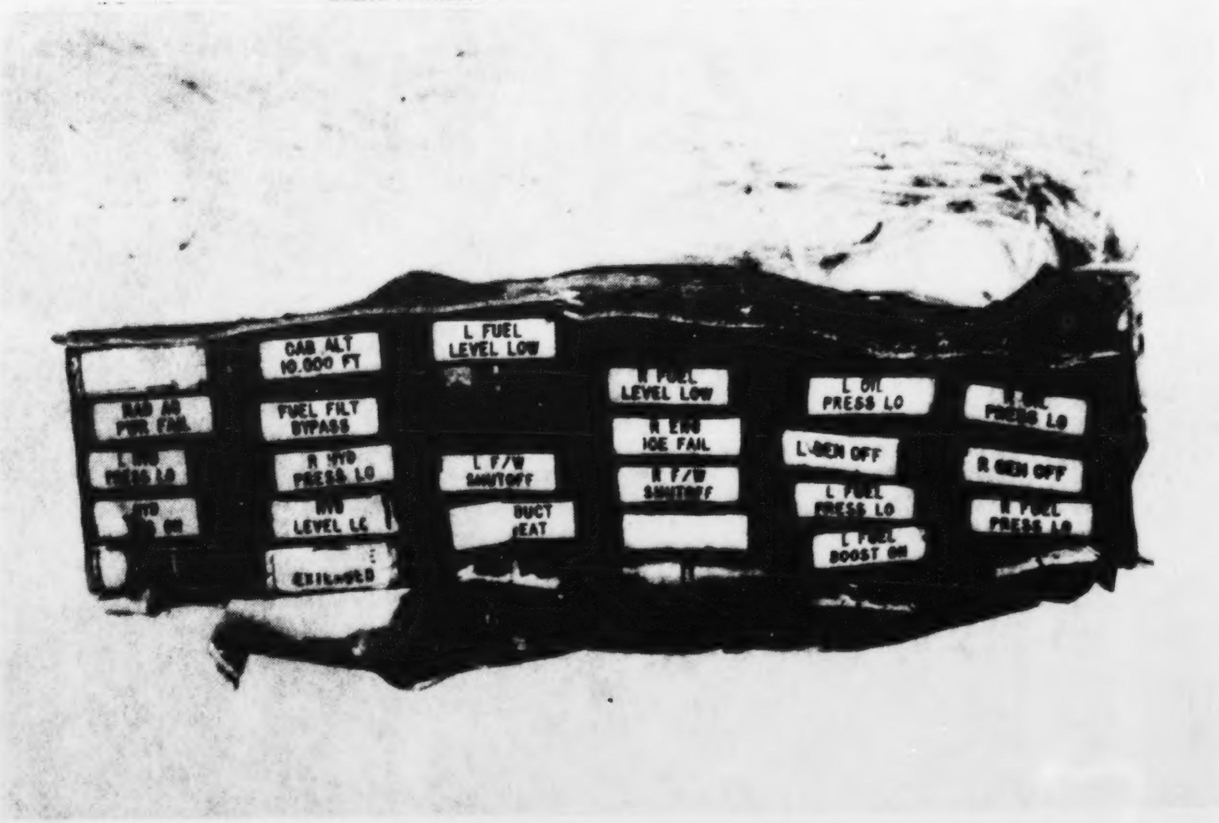

CAB ALT
10,000 FT
L FUEL
LEVEL LOW
R FUEL
LEVEL LOW
L OIL
PRESS LO
FUEL FILT
BYPASS
R ENG
ICE FAIL
L GEN OFF
R GEN OFF
R HYD
PRESS LO
L F/W
SHUTOFF
R F/W
SHUTOFF
L FUEL
PRESS LO
R FUEL
PRESS LO
LEVEL LO
DUCT
EAT
L FUEL
BOOST ON

FIGURE 2 - ANNUNCIATOR PANEL RETRIEVED FROM THE WRECKAGE OF A CESSNA CITATION

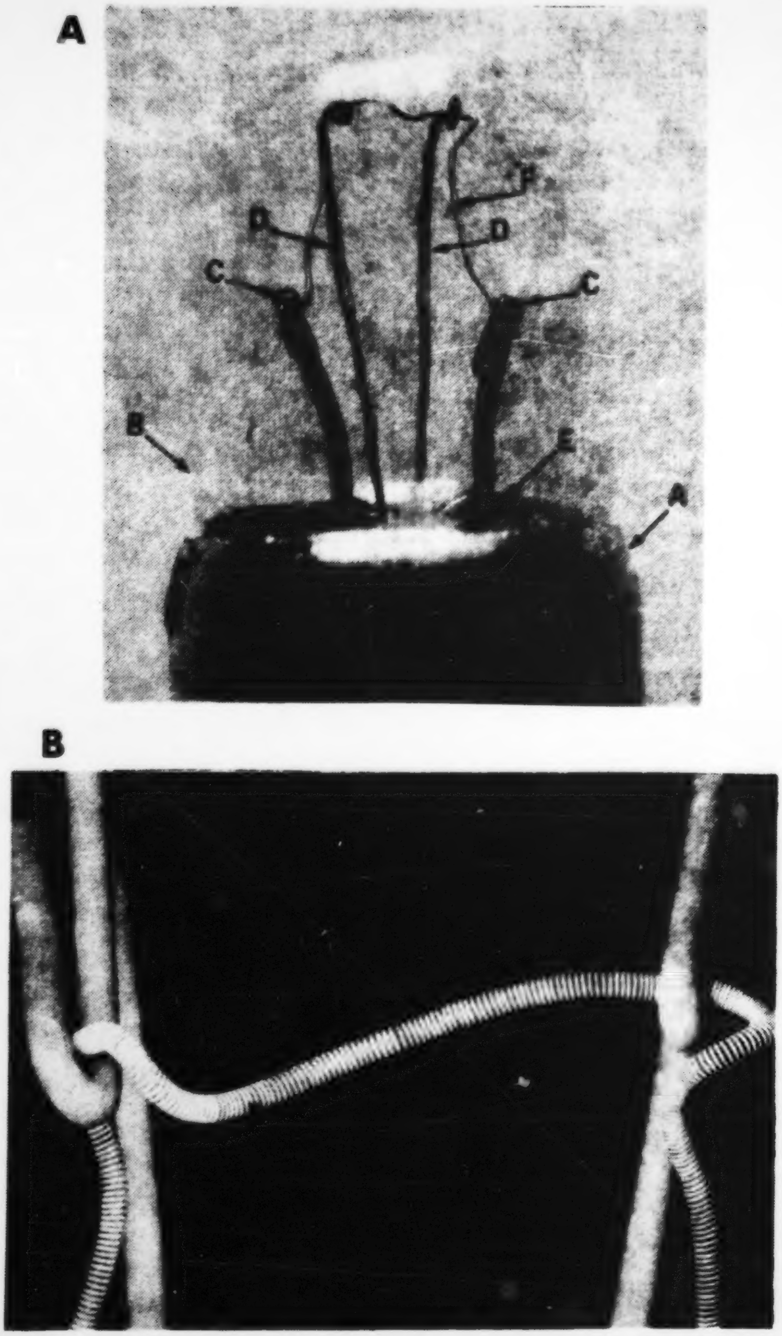


FIGURE 3 - A) GE-327 LIGHT BULB WITH INTERNAL COMPONENTS IDENTIFIED AS "A" BASE, "B" GLASS ENVELOPE, "C"CONTACT POSTS, "D" SUPPORT POSTS, "E" MOUNTING BEAD, "F" FILAMENT.

B) COILED TUNGSTEN FILAMENT PASSING THROUGH THE TWO SUPPORT POSTS. 60X support posts are not used in some bulbs, such as those with a C-2R configuration, where the filament runs in a slight arc between the two contact posts. Support post movement at impact typically causes damage to a supported filament which would not have been damaged in a C-2R configuration bulb. The 327 bulb is classified as a T-1 3/4 bulb, which means that the bulb diameter is 7/32" (5.5 m). This is calculated by dividing the "T" number by 8.

1.6 For this report, the impact testing was largely confined to GE-327 light bulbs and all analysis refers to this type of bulb unless otherwise stated.

2.0 FILAMENT MANUFACTURE

2.1 Although there are numerous types of light bulbs, the tungsten filament for sub-miniature bulbs is manufactured in essentially the same way. Since most of the damage incurred by light bulbs in aircraft accidents is directly associated with the filament, a review of the filament manufacturing process is in order. The tungsten filament is generally manufactured by a powder metallurgy process. Tungsten has the greatest high temperature tensile strength of all metals (above 1650°C or 1923°K) and the highest melting point of any metal (3140°C or 3413°K). The tungsten is generally received at the lamp factory as a fine 'fibrous' wire that consists of body-centred cubic crystals that were elongated and deformed during the various heat treatments and drawing processes. The wire is further drawn (eg: 0.008mm or 0.0003" dia. for the 327 type filament) at the lamp plants, and is usually coiled around a molybdenum mandrel, which is later dissolved away by acid. A technique called 'flashing' is used by the industry to heat the filament above its recrystallization temperature. The crystals or grains will grow larger with increased flashing. In order to prevent grain boundaries forming in planes perpendicular to the wire axis, dopants such as potassium, silicon and aluminum are added in extremly small quantities. As the wire is drawn to smaller diameters, it becomes relatively more ductile at room temperatures and the temperature required for recrystallization increases. Ductile to brittle transition temperatures generally range from 250°C (523°K) to 350°C (623°K) for tungsten, while recrystallization temperatures can vary from 1000°C (1273°K) to 2000°C(2273°K). The main purpose of flashing is to create long interlocking grains to improve sag resistance characteristics (by increasing Young's modulus); however there is a tradeoff. Long interlocking grains produce a weaker filament than a fine grain microstructure. Both the support posts suspending the filament and the contact posts act as heat sinks (see Figure 4) which prevent the filament from reaching recrystallization temperatures in these local regions, hence a non-uniform recrystallization occurs along the filament length.

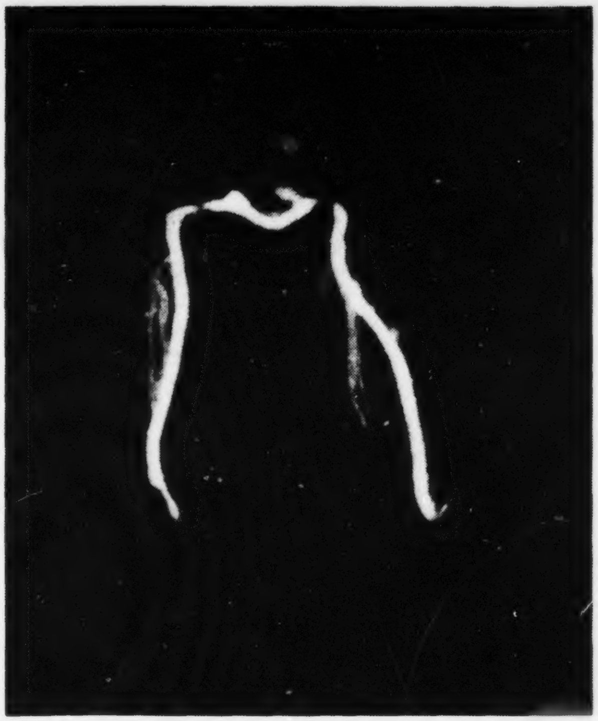


FIGURE 4 - FILAMENT BURNING AT 28 VOLTS D.C. SHOWING HEAT SINK EFFECTS OF THE SUPPORT POSTS AND CONTACT POSTS. CLOSE OBSERVATION REVEALS THAT THE COILS ADJACENT THE 'HEAT SINKS' ARE COOLER.

3.0 FILAMENT OPERATION

3.1 The GE-327 light bulb and most of the lights found in aircraft annunciator panels operate on 28 volts direct current (d.c.); however, some are equipped to operate on alternating current (a.c.) at 400 Hz. Some annunciator panels are also equipped with a three position switch (test, bright and dim). The test position applies voltage to all of the lights as an operational check; the bright position allows a potential of 28 volts to be applied to the indicator if triggered; and the dim position prescribes a potential of less than 28 volts by switching a resistance in series with most of the lights. This latter position provides reduced light output for night flying, for example. The light output varies in direct proportion to the 3.6th power of the applied voltage.

$$\text{i.e. Candle Power} = \left[\frac{V_d}{V_a}\right]^{3.6} \times \text{Candle power at } V_d$$

where V_d = design voltage
V_a = applied voltage

The temperature of the filament is also a function of the applied voltage. Figure 5 shows the relationship between voltage and temperature for the GE-327 light bulb. From Figure 5, it can be seen that at 28 volts d.c. the filament temperature is approximately 1960°K. Reduced voltage will obviously decrease filament temperature and therefore should be considered during light bulb analysis.

3.2 Most miniature bulb filaments, including the GE-327, operate in a vacuum. Since this environment, inside the glass envelope, is not a perfect vacuum, some H_2O may still be present. This will combine with the tungsten at operating temperatures and cause the filament to gradually 'evaporate' and become thinner (known as the water cycle). The tungsten oxides usually deposit on the inner glass envelope and hence a dark silver color is often evident on older bulbs. The reduction in bulb life due to the gradual evaporation of tungsten is usually estimated with the 12th power rule (Chicago Miniature catalogue no 7700).

$$^{*}\ \text{Rerated Life} = \left[\frac{V_d}{V_a}\right]^{12} \times \text{Life at } V_d$$

* NOTE: This formula is based on a.c. voltage

VOLT	AMP (mA)	RESISTANCE (ohms)	RESISTIVITY (u ohm cm)	TEMPERATURE (kelvin)
0.0	0.00	73.0	5.66	300
2.0	10.56	189.4	14.68	651
4.0	13.36	299.4	23.30	942
6.0	16.14	371.8	28.81	1129
8.0	18.82	425.1	32.94	1263
10.0	21.33	468.8	36.33	1372
12.0	23.63	507.8	39.36	1468
14.0	25.78	543.1	42.09	1554
16.0	27.83	574.9	44.56	1631
18.0	29.76	604.8	46.88	1703
20.0	31.60	632.9	49.05	1769
22.0	33.39	658.9	51.06	1831
24.0	35.94	667.8	51.75	1852
26.0	37.62	691.1	53.56	1900
28.0	39.21	714.1	55.34	1960
30.0	40.78	735.7	57.01	2010

NOTE: BASED ON FILAMENT LENGTH OF 29.3cm CALCULATED FROM ROOM TEMP. RESISTANCE AND .0017cm DIA. TEMP. VS RESISTIVITY FROM E-230 PHYSICS HAND BOOK 56th EDITION.

VOLTAGE VS. TEMPERATURE (GE-327)

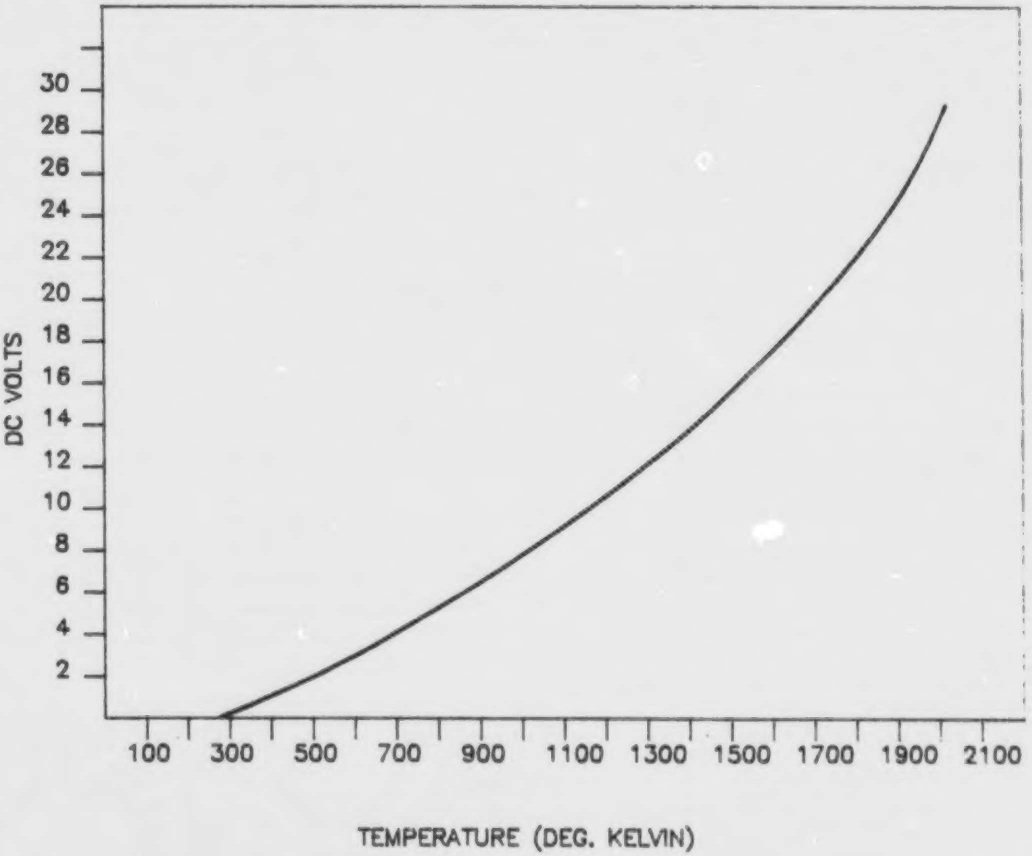


FIGURE 5 - Voltage - temperature relationship for GE-327 bulb.

Should the glass envelope break or develop a leak, a hot filament will become exposed to the atmosphere, and instant oxidiation and burn-out would occur. In most aircraft accidents, the glass envelope remains intact.

3.3 When operating a bulb on d.c., present theory suggests that the resulting unidirectional magnetic field causes tungsten ions to migrate to preferred crystal planes. This electromigration causes the filament surface to develop jagged, saw tooth irregularities. This appearance is commonly referred to as "notching" and increases with burning time (see Figures 6-11). D.C. notching will drastically reduce the life of bulbs compared to their longevity operating on a.c., and most life ratings given by lamp manufacturers are thus based on a.c. operation. The temperature which provides sufficient energy to allow molecular rearrangement is the recrystallization temperature. This rearrangement occurs in two basic ways. First, at elevated temperatures (ie. above recrystallization) crystal growth occurs, altering the microstructure from fine grained to coarse grained, composed of fewer and larger crystals. These crystals can grow to encompass several turns of the coiled wire. Second, the crystals' resistance to recrystallization comforming to any curved surface (coiled wire) during molecular rearrangement results in the development of notching in repetitive patterns. These extremely repetitive patterns over several coils are considered to be the result of notching developing on one large crystal of several coils length. This type of notching does not occur when operating on a.c., because under the influence of the cyclically reversing current the net migration is essentially zero. Some a.c. notching does, however, still occur near the contact posts and support posts where thermal gradients exist. (The transportation of a liquid, gas or solid due to thermal gradients is known as the 'Soret Effect'). Notching (a.c. or d.c.) does not occur in the coils directly adjacent the support posts and contact posts because the local filament temperature in these areas does not reach recrystallization temperatures due to the heat sink effect. The major difference between a.c. and d.c. notching is that in a.c. the filament will only notch in the small thermal gradient areas, while d.c. notching will occur along virtually the entire filament length.

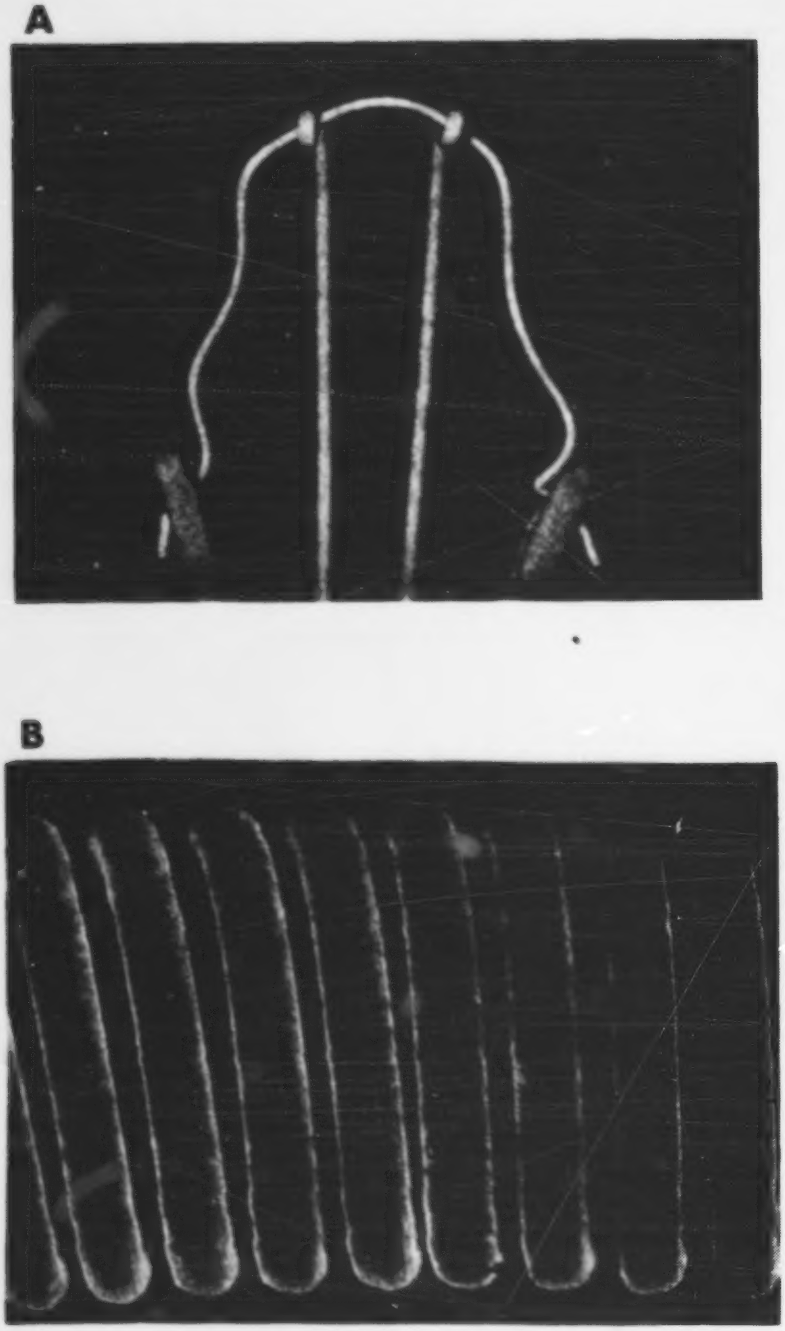


FIGURE 6 - A) NEW FILAMENT AT 20X.
B) ENLARGED VIEW OF FILAMENT AT 1000X.

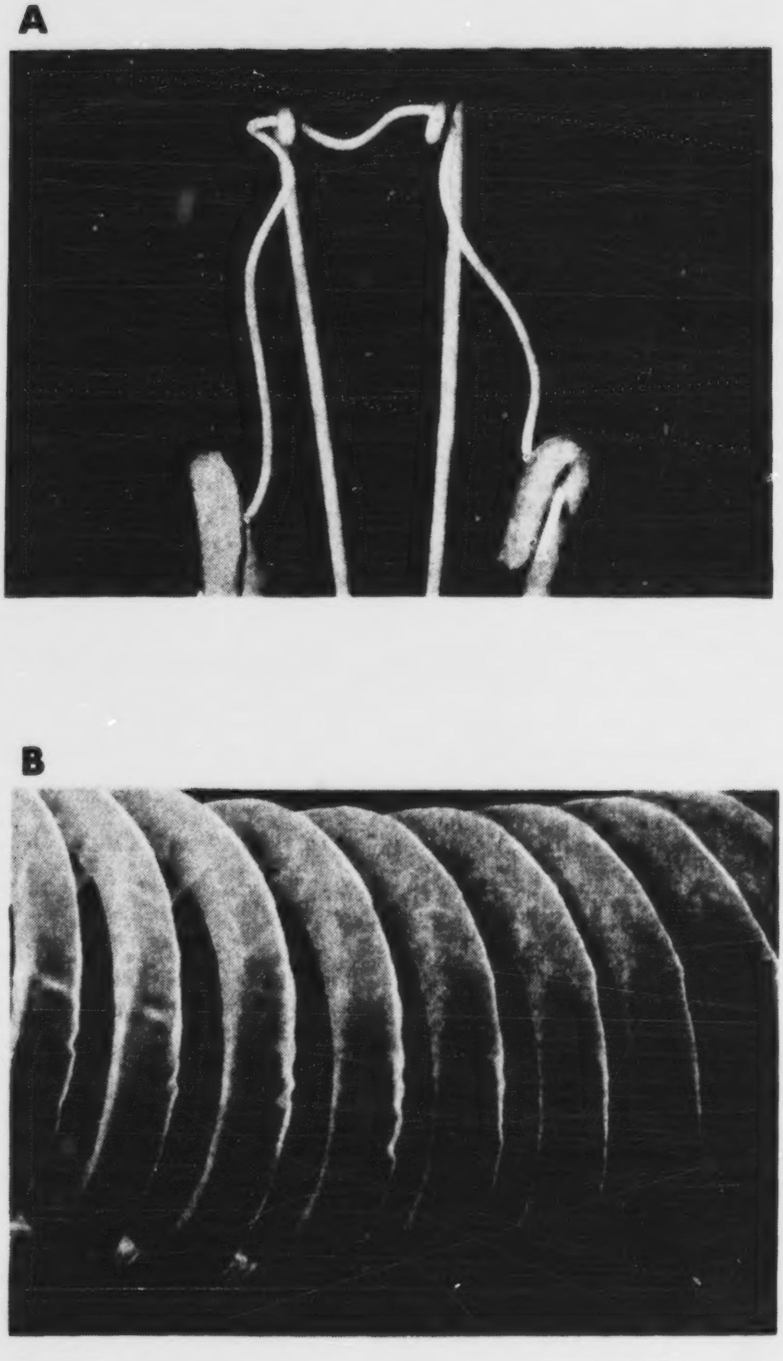


FIGURE 7 - A) FILAMENT AGED 48 HOURS AT 28 VOLTS D.C. 20X.
B) ENLARGED VIEW OF THE SAME FILAMENT. NOTICE THE NOTCHED APPEARANCE DEVELOPING ACROSS THE FILAMENT SURFACE. 1000X.

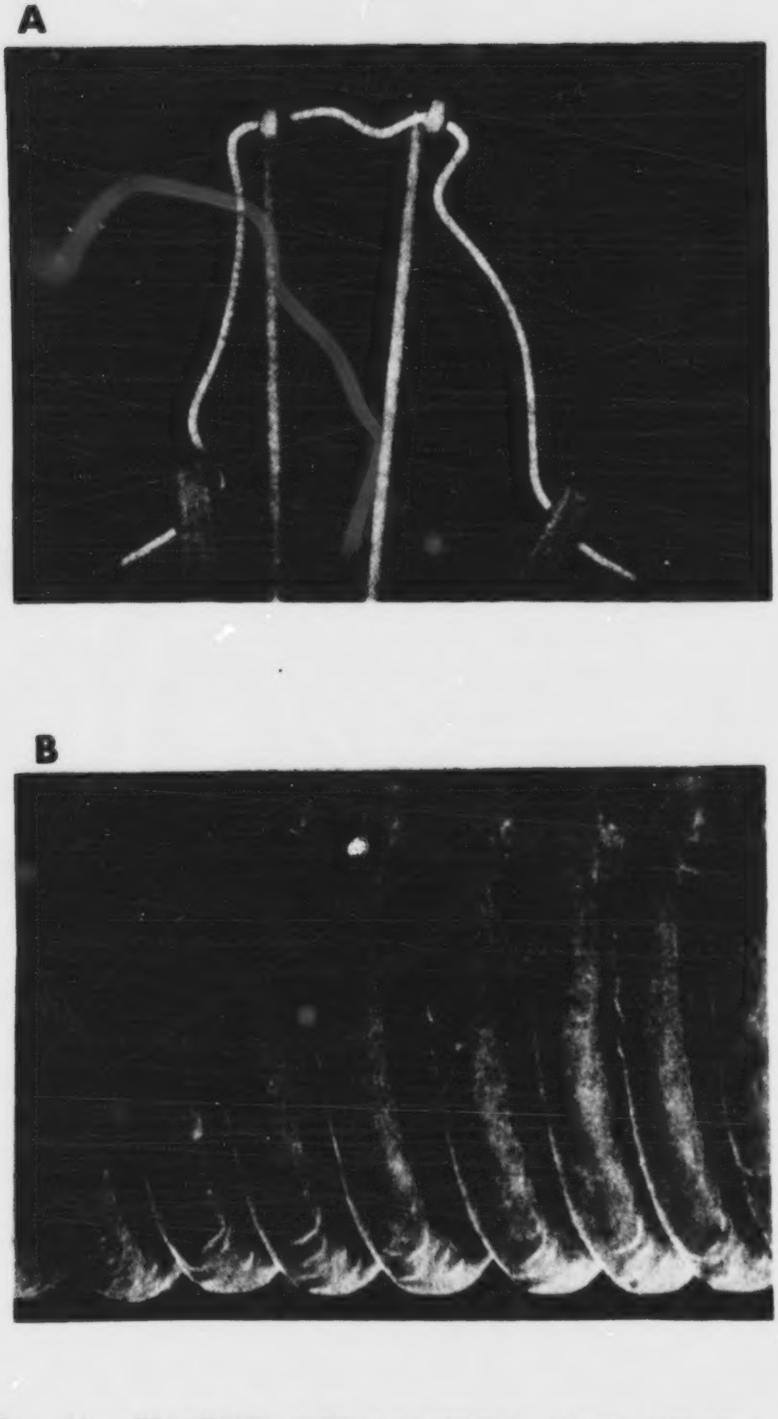


FIGURE 8 - A) FILAMENT AGED 144 HOURS AT 28 VOLTS D.C. 20X.
B) ENLARGED VIEW OF THE SAME FILAMENT. 1000X.

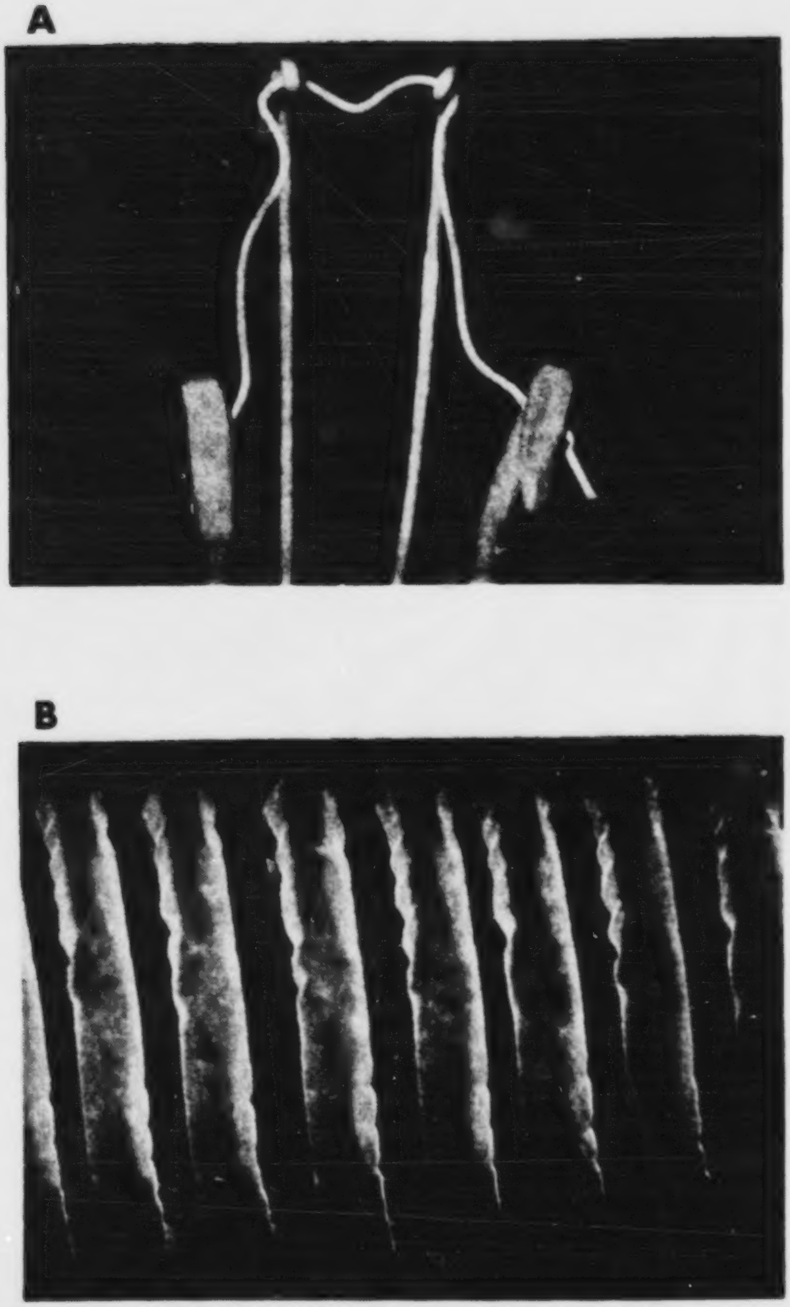


FIGURE 9 - A) FILAMENT AGED 210 HOURS AT 28 VOLTS D.C. 20X.
B) ENLARGED VIEW OF THE SAME FILAMENT. 1000X.

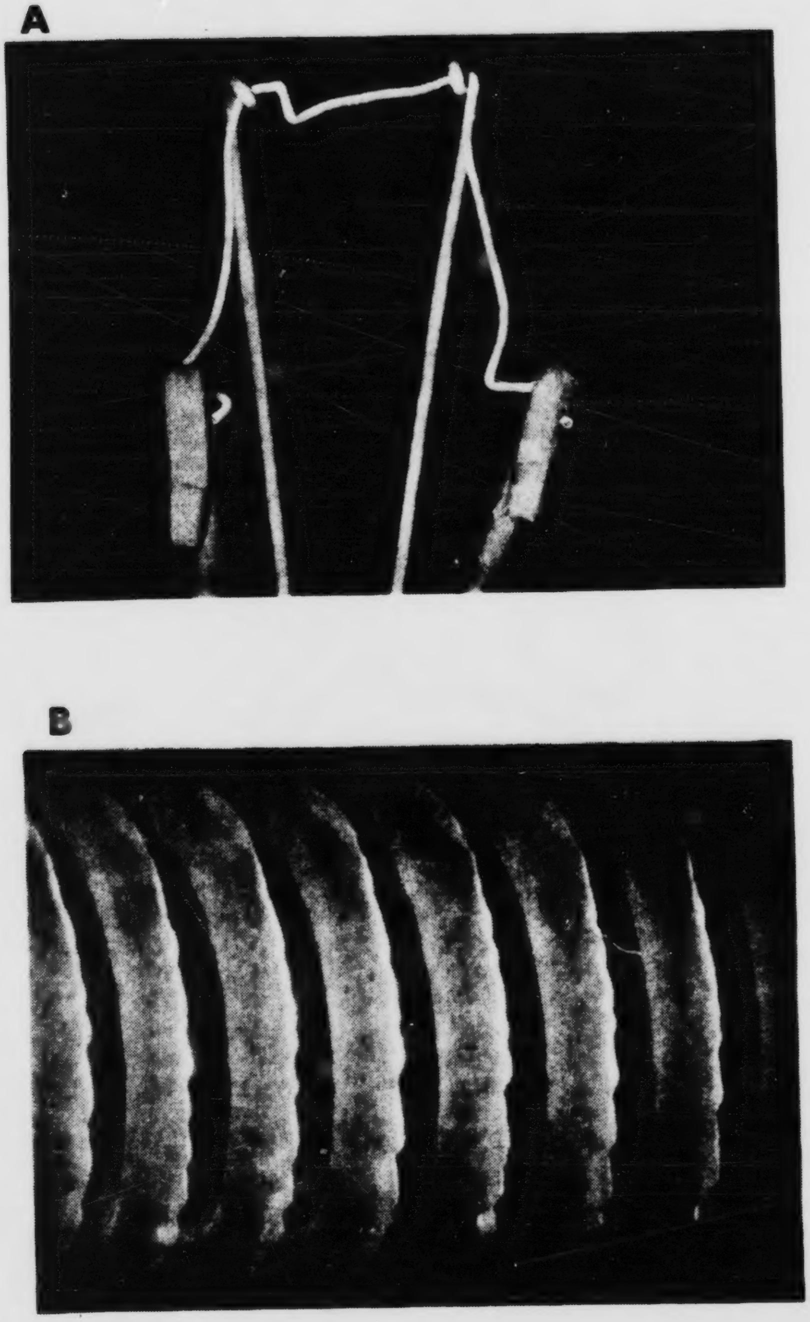
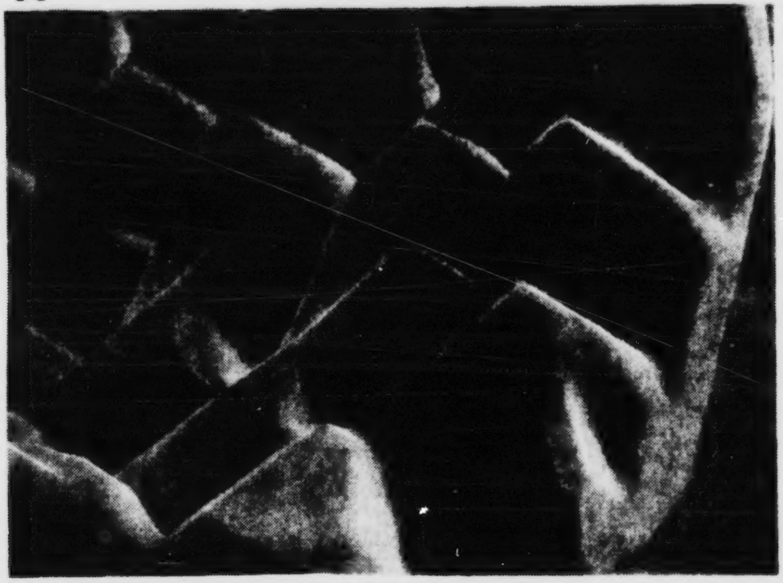


FIGURE 10 - A) FILAMENT AGED 250 HOURS AT 28 VOLTS D.C. NOTICE THE FILAMENT DISTORTS WITH AGE AND 'CURLS' AROUND SUPPORTS AND CONTACTS. 20X.
B) ENLARGED VIEW OF THE SAME FILAMENT. 1000X.

A



B

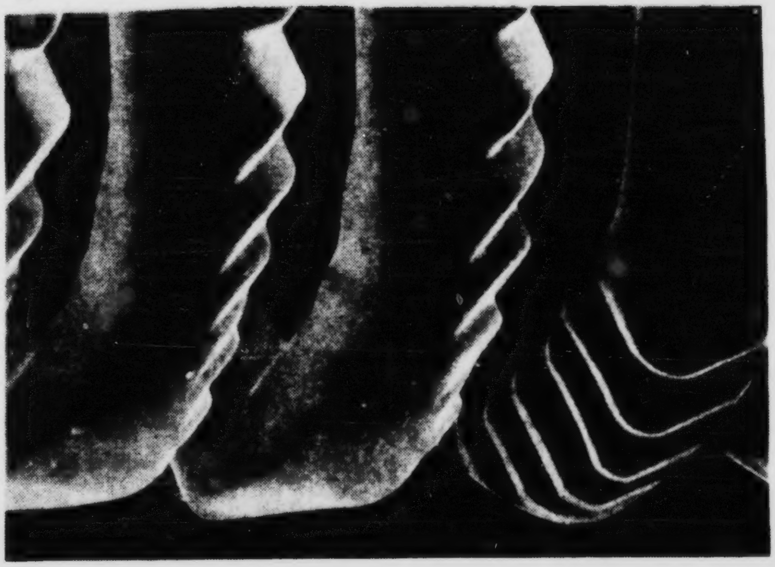


FIGURE 11 - A) SEVERE NOTCHING ACROSS A FILAMENT AGED 506 HOURS AT 28 VOLTS D.C. (2500X)

B) FILAMENT AGED 77 HOURS AT 38 VOLTS D.C. NOTICE THE UNIFORMITY OF THE NOTCHING PATTERNS. (X2000)

The d.c. notching is also more structured in that the notches point in the direction of current flow. A filament operated on d.c. will become weaker much faster and have a much shorter life span, as d.c. notching becomes the predominant life-influencing mechanism. Operating a filament at higher voltages/temperatures will result in increased notching as shown in Figure 11(b). The degree of notching is independent of wire diameter; hence it affects sub-miniature light bulbs such as those found in annunciator panels (e.g. GE-327s) much more than larger diameter filament bulbs. The filament is weakened by localized reduction in cross-sectional area. Severity of notching is a measure of the amount of burning time above the filament's recrystallization temperature which generally corresponds to the filaments age.

3.4 Another important observation noted during the aging tests was the general distortion of the filament shape, particularly around the support posts and contact posts (heat sink areas) as is evident in Figures 7 through 10. This general deformation due to age must not be confused with impact deformation caused during a crash. As bulbs age at operating voltages the filaments tend to curl around the support posts and contact posts, even to the extent that a loop can be formed.

4.0 VIBRATION AGING

4.1 In order to obtain a realistic sample group of light bulbs for impact testing, bulbs were aged (at 28 volts d.c.) for up to 500 hours, while simultaneously being subjected to vibrations at frequencies and magnitudes characteristic of those encountered in actual aircraft instrument panels. Not much information on vibration levels in the cockpit area was available. Flights were taken on a small cross-section of available Transport Canada aircraft, such as a Bell 206, King Air, Queen Air, and Twin Otter, and the instrument panel vibrations were measured in all three axes of flight. Generally, vibrations on these aircraft were below 300 hz and at relatively low g levels. The helicopter vibrations in the direction of flight were on average about 2 g, the highest average measured. Literature suggests that the maximum g levels typically found on instrument panels is about 5 g. From the data above, it was decided to vibration age light bulbs at 28 volts d.c., at 5 g constant acceleration, with a sweep frequency of 5-300 Hz to simulate the "worst case" operational environment of an aircraft instrument panel. The vibration levels described above are relatively low, and stereo-microscopic examination after vibration-aging revealed no apparent vibration induced damage on all of the lights tested. The vibration apparatus is shown in Figure 12.

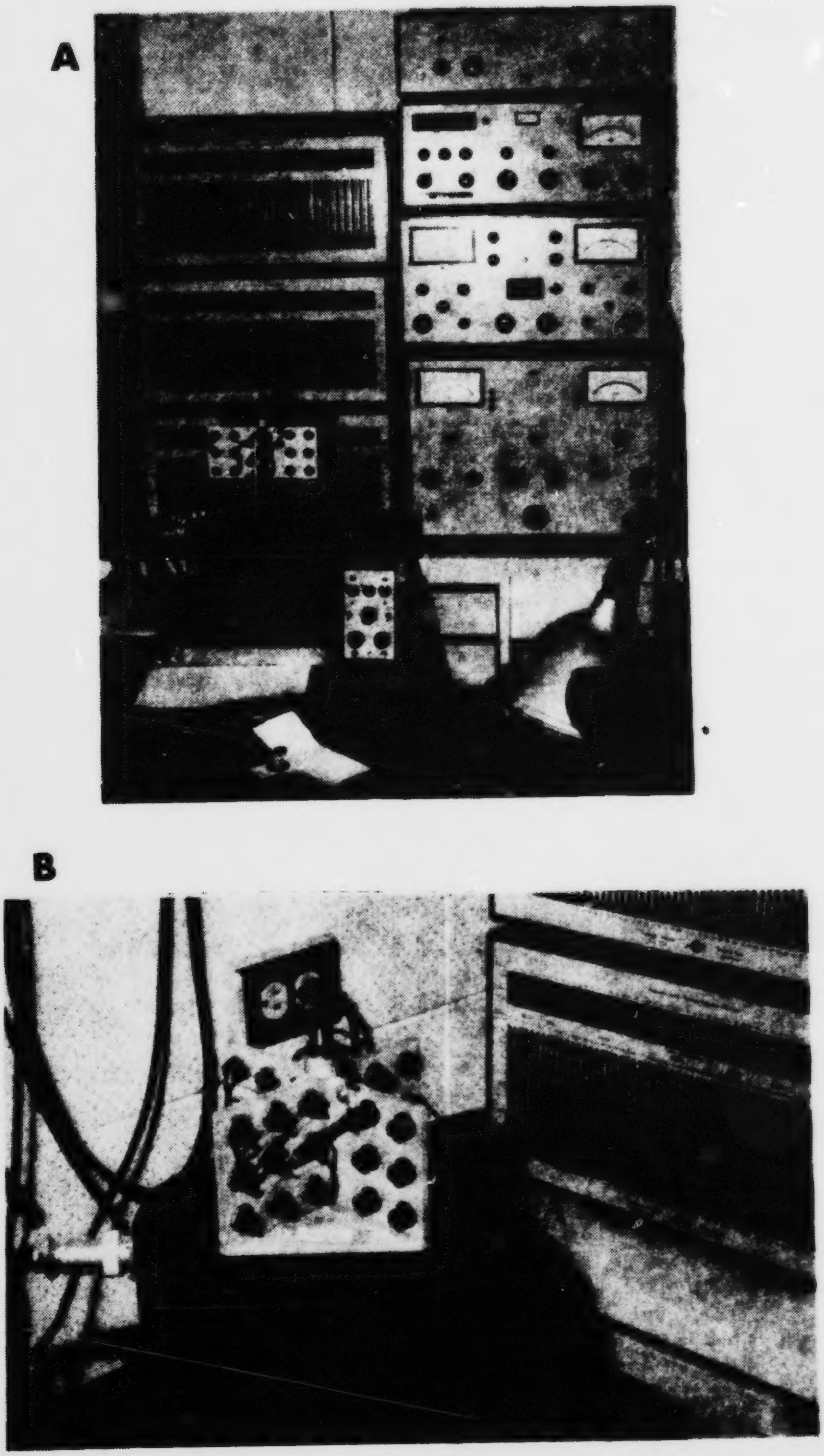


FIGURE 12 - A) VIBRATION TESTING EQUIPMENT. GENERAL SET-UP SHOWING SMALL SHAKER TABLE AND TOP OF LARGE SHAKER TABLE.
B) CLOSE-UP OF LIGHT BULBS BEING VIBRATION AGED ON SMALL SHAKER TABLE.

5.0 RESONANCE TESTING

5.1 As a result of high speed cinematography tests conducted to observe the behaviour of the light bulbs' internal components during an impact, it was discovered that support post movement has a large effect on the deformation of the filament. Should the support posts attain their natural frequency, the filament deformation can be dramatic. A large shaker table, capable of producing approximately 100 g, was used to determine the resonant frequencies of the 327 light bulbs' internal components. The resonances were observed by using synchronized strobe lights.

5.2 New bulbs were tested to determine the different modes of resonance and respective frequencies. They were tested in both an "on" and "off" state, and were subjected to a sinusoidal signal from 150 to 8500 Hz at a constant acceleration of 200 m/s^2 (20.4 g). The major components of interest were the filament itself and the support posts; however, all of the internal components typically interact to establish a relatively complex system. The resonant frequencies were defined as any frequency that caused a significant uniform or periodic response of the system. For any system, no matter how complex, there is only one resonant frequency for each mode of resonance. Due to the non-rigid filament system, it was found that there were a large number of modes; however, by far the largest responses occurred at approximately 1300 Hz and 1550 Hz as these two frequencies caused the support posts and filament to oscillate violently. Figure 13 shows a histogram for bulbs of all ages and the two resonant frequency distributions. The range of these resonant frequencies were found to be about ± 50 Hz (within one standard deviation). Tests showed that the resonant frequencies were not significantly affected by either filament age or temperature ("on" or "off"). This is consistent with the observations that the major resonances (1300 and 1550 Hz) are largely related to the support posts, and hence age and filament temperature would likely not play a significant role.

5.3 Although the light bulb is a relatively complex system, three distinct modes of the support post resonance were observed:

a) lateral movement, both posts in and out of phase;
b) backwards and forwards, both posts in and out of phase;
c) rotation of the posts. (a and b combined out of phase).

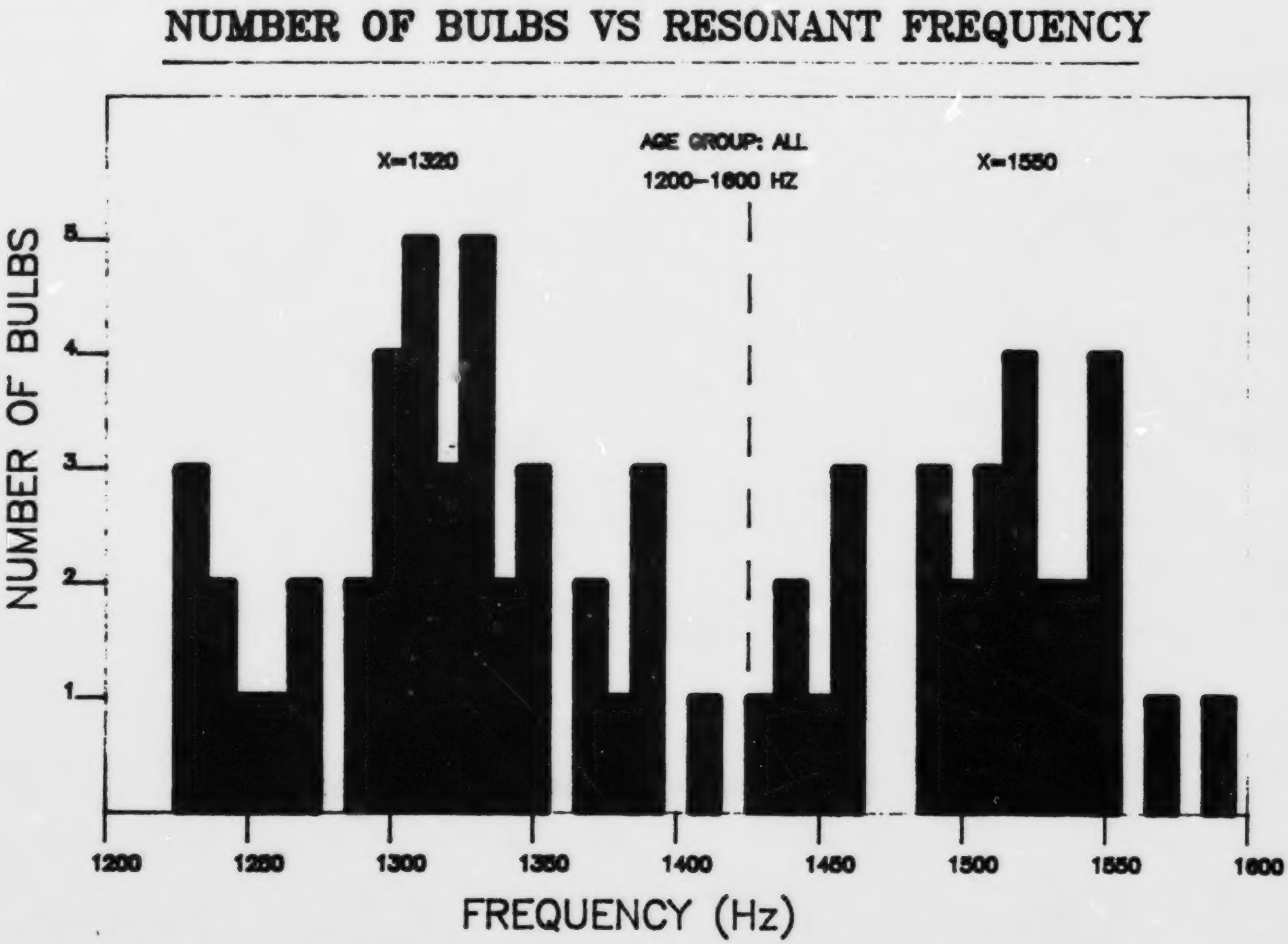


FIGURE 13 - Resonant Frequency Distribution for GE-327 BULB.

No single mode could be attributed to a specific frequency; however, depending on the orientation of the bulb, one mode predominated over another. When the plane of the supports was in line with the direction of vibration, the lateral mode prevailed; when the plane of the support posts was perpendicular to the direction of vibration, the backwards-forwards mode predominated; when the bulb axis was in line with the vibration, rotation of the posts occurred. The latter mode did not produce as high a response as the other two modes.

5.4 While vibrating the bulbs at the frequencies which produced the highest response, it was found that hot filaments deformed more easily than cold ones. With cold filaments, no significant deformation was observed even when vibrated to filament fracture (see Figure 14a). Hot filament deformation generally occurred in the form of filament stretch and uncoiling (see Figure 14b). It was also observed that the acceleration level required to fracture a filament (either hot or cold) decreased with the age of the filament. New filaments, for example, could not be damaged, when cold, at the maximum g level of the shaker (= 100g), whereas a 5-10 g vibration level fractured a 210 hour aged filament instantaneously. Even in an aged condition, however, filaments were able to withstand maximum shaker table acceleration without showing any signs of damage when the frequency of excitation was not a natural frequency of the system. These g levels obtained on the shaker table cannot be compared directly to impacts produced by the laboratory impact machine or the impacts experienced during actual aircraft crashes because the shaker system is continually providing a sinusoid. An impact transient would require much higher g levels to cause the same damage.

5.5 During tests, it was discovered that the filament frequently broke when the power supply was terminated while the bulb was being subjected to vibration at resonant frequencies. The resulting deformation was hot induced filament stretch during the "on" condition, with fracture occurring during the transition from 28 volts to 0 volts. This transition period was measured and was found to be greater than 100 milliseconds as the power supply drained. A bulb which could not be fractured during the "on" condition, would fracture when introduced to the shock of terminating power. This shock may be due to the filament coils sudden inductive change and consequent magnetic forces in combination with the vibrating forces. The consequences of a light bulb's supply voltage changing during an impact sequence is discussed under incandescence-time tests discussed later in this report.

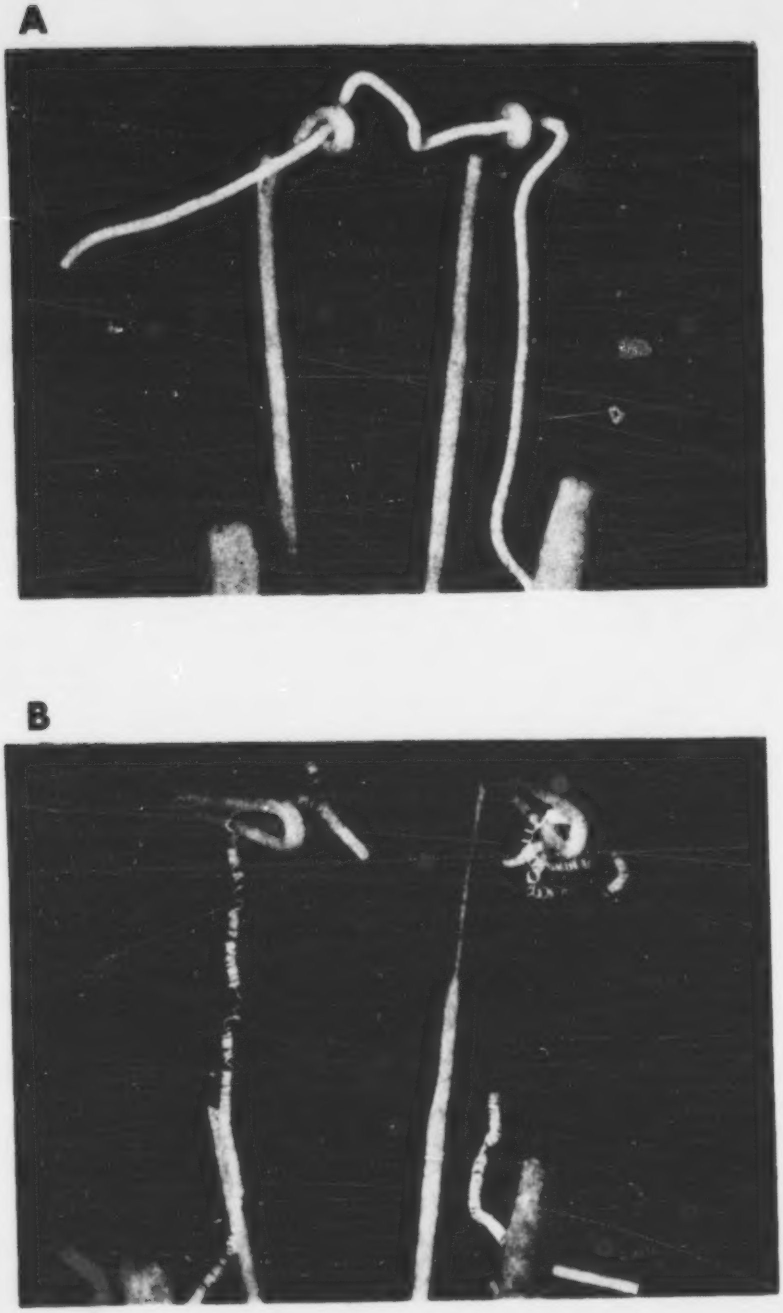


FIGURE 14 - TWO FILAMENTS AGED 250 HOURS SUBJECTED TO EXCITATION AT 1350 HERTZ WHILE COLD (A) AND AT 28 VOLTS DC (B). BOTH FILAMENTS HAVE FRACTURED BUT THE HOT BULB SHOWS SIGNS OF FILAMENT DEFORMATION.

6.0 IMPACT TEST PROGRAM

6.1 The major test apparatus used in the light bulb study consisted of a one meter drop impact tester which produced decelerations up to 4000 g over approximately 0.7 milliseconds (half sine). The drop table was allowed either to free fall or was additionally accelerated downwards by means of elastic shock cords. The table impacted onto an elastomer pad of selected hardness and thickness that produced a sinusoidal deceleration-time history. Figure 15 shows the impact machine and related instrumentation and measurement equipment. This type of impact machine subjected the light bulbs to an inertial impact as opposed to a direct impact. A direct impact would be, for example, when the headlights of a car 'directly impact' an oncoming car. The tail lights in this example would experience an inertial impact. Direct impacts generally cause glass envelopes to break, and foreign materials may make direct contact with the filament and damage it.

6.2 The elastomer pad that arrests the impact table can be considered as simulating a weightless linear spring for the purpose of analysis of impact forces. When a rigid body (the impact table) impacts onto such a spring, the result is a deceleration pulse in the shape of a half-period sine wave. High frequency components can often be found superimposed on the basic sine pulse due to the table and system not being perfectly rigid. During high g level impacts 'ringing' can also occur. When the table is in its raised position, above the elastomer pad, the table possesses a potential energy, namely:

$$P.E. = mgh$$

where P.E. = potential energy
m = mass of table
g = acceleration due to gravity (9.81 m/s)
h = drop height (one meter)

$$T.E. = PE + KE$$

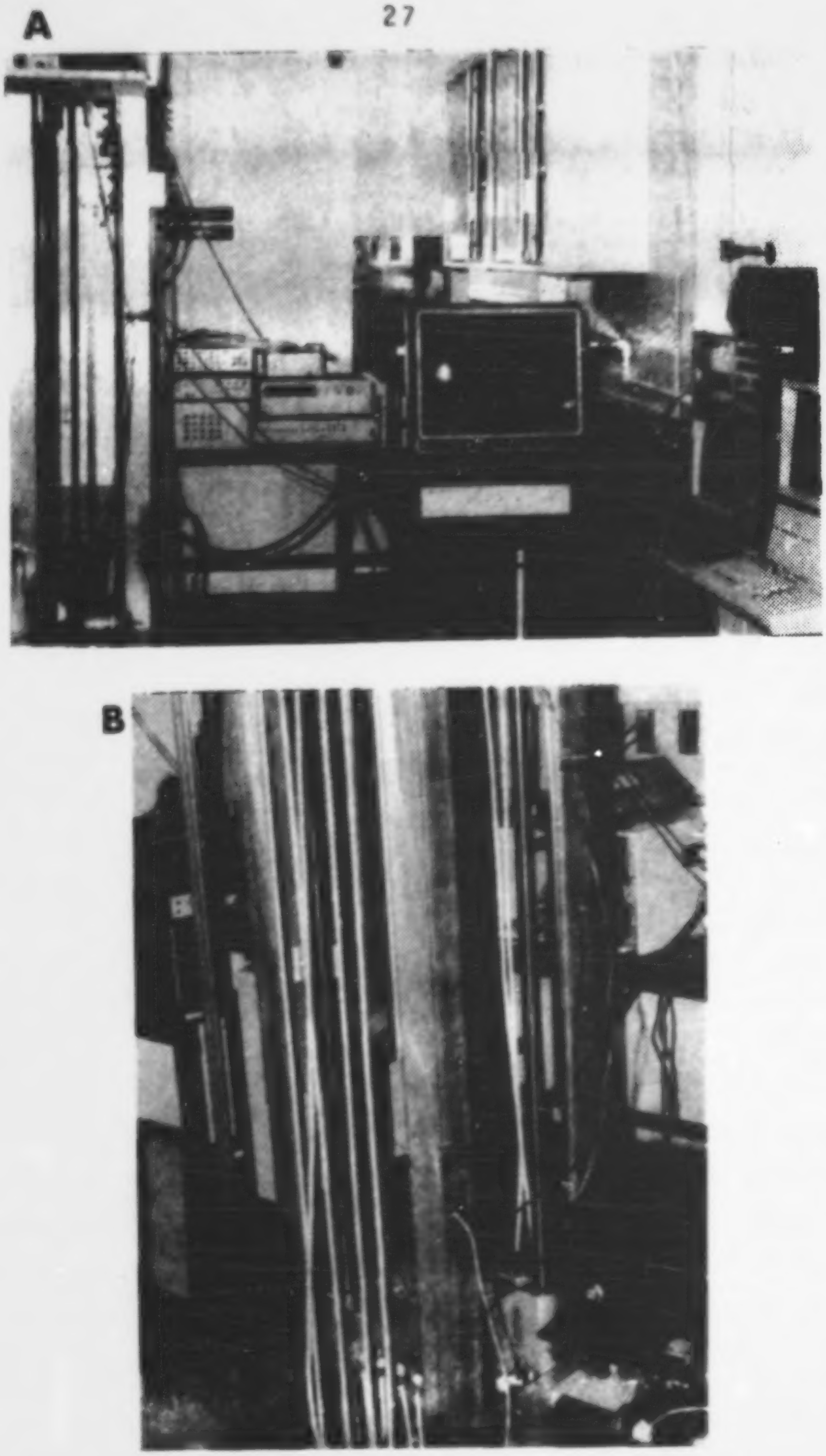


FIGURE 15 - A) IMPACT TEST MACHINE AND RELATED INSTRUMENTATION.
B) CLOSE UP OF IMPACT TEST MACHINE.

where T.E. = total energy and K.E. = kinetic energy and initially KE = 0 (when the table is in the raised position)
(Note: - When shock cords are added to the table to aid in downward acceleration, the additional energy available invalidates the following equations).

During the drop the potential energy becomes kinetic energy;

$$KE = \tfrac{1}{2} mv^2$$

where KE = kinetic energy
v = velocity

At the moment of impact:

$$PE = 0$$
$$KE = TE - PE$$
$$\therefore \quad KE = TE$$

$$\therefore \quad mgh = \tfrac{1}{2} mv^2$$

$$\therefore \quad v^2 = 2gh$$

For a triangular (sawtooth) acceleration time pulse (no rebound) the area under the curve, $\tfrac{1}{2}$ at, is equal to the velocity prior to impact:

$$v = \tfrac{1}{2}at$$

where a = peak acceleration
t = time duration

Hence, for a given potential energy, a maximum velocity just prior to impact can readily be calculated. This velocity will allow for an infinite number of triangular acceleration-time pulses from $v = \tfrac{1}{2}$ at. These equations, however, do not exactly hold for a half sine wave because the area under a sine wave pulse measures the total velocity change including rebound and will thus be higher than that calculated from the potential energy. Also, the elastomer pads have relatively high energy losses associated with them. These equations, however, served to provide approximations for the impact pulse ranges to be expected from the machine.

6.3 The instrumentation used with the impact machine consisted of two accelerometers (Bruel & Kjaer): one mounted directly on the drop table, and one mounted directly on the fixture that housed the light bulbs under test (Figure 16a). The accelerometer signals were fed through charge amplifiers with appropriate filters and processed by a dual channel spectrum analyser (Bruer & Kjaer type 2037) and further processed and stored by a Hewlett-Packard 9836 computer (see Figure 16b). Impact tests utilized a 3000 Hz cut-off filter to eliminate ringing and accelerometer resonances, while for g levels above approximately 1000 (short duration) a 10,000 Hz cut-off filter was used to ensure that the fundamental pulse shape was not significantly altered. Figure 17 shows a typical sinusoidal impact of half-period duration as processed by the computer.

6.4 A considerable amount of initial impact testing was carried out while developing the test procedure and writing the computer software to process data and control the test. Once the test procedure was developed and verified, over 400 GE-327 bulbs were impact tested. Some of the problems encountered obtaining reliable data are of interest. Initial tests were done with a piezatron accelerometer and a 1000 hertz built-in filter that was available. This accelerometer/filter did not provide reliable data for the higher g level impacts due to the short durations involved. The 1000 hertz filter was suppressing and distorting the fundamental sine pulse. New accelerometers were therefore obtained which were capable of measuring 5000 g with a variety of cut-off filters. Another major problem was the test fixture itself. The original fixture contained complex resonances when subjected to high g level short duration impacts for which it was not intended. As a result, a new fixture was designed and manufactured essentially out of a block of solid aluminum which contained no resonances below

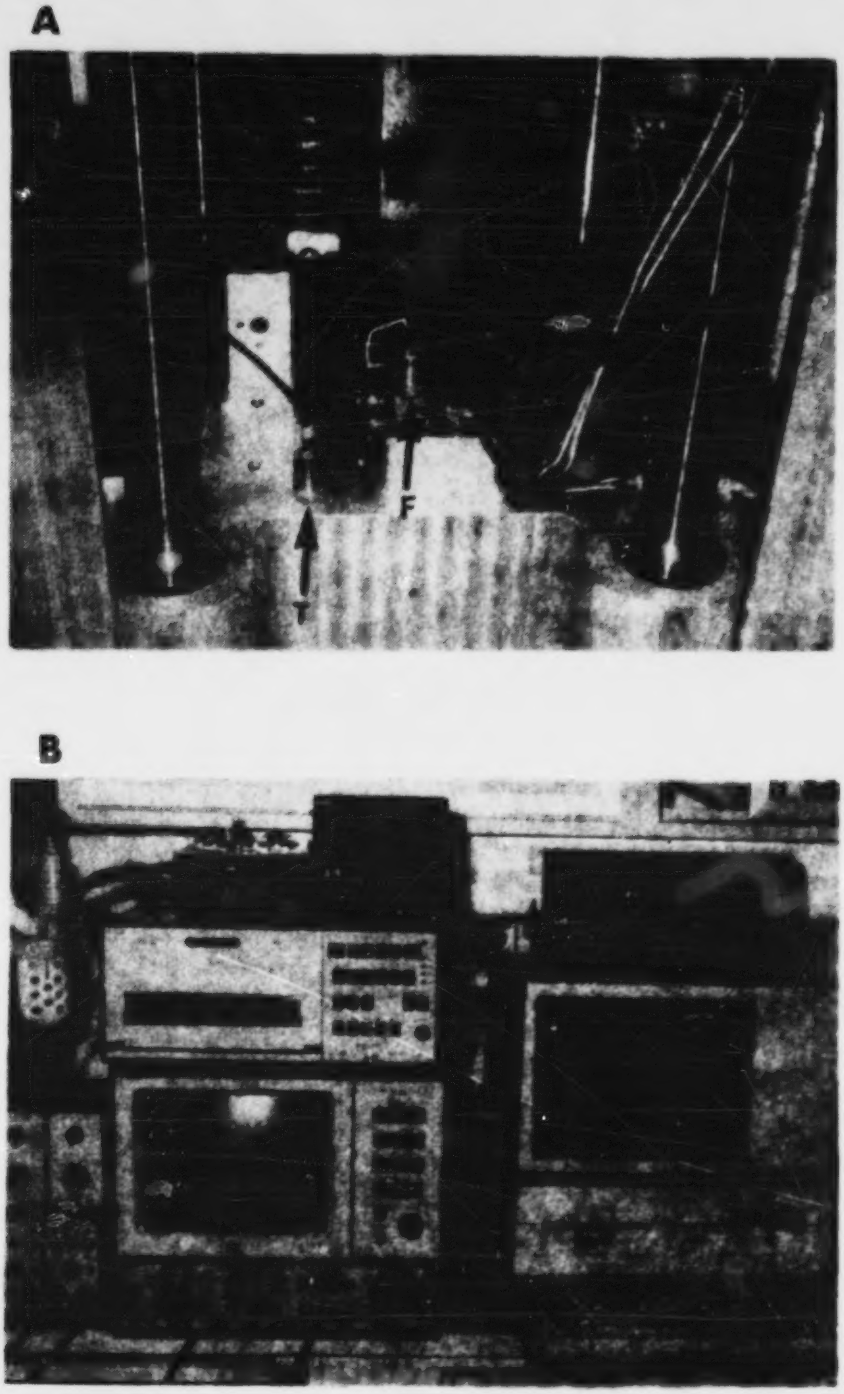


FIGURE 16 - A) ACCELEROMETERS MOUNTED ON IMPACT TABLE (T) AND FIXTURE (F) THAT HOUSED THE FOUR LIGHT BULBS UNDER TEST.
B) SPECTRUM ANALYSER AND COMPUTER THAT ACCEPT AND PROCESS THE ACCELEROMETER PULSE.

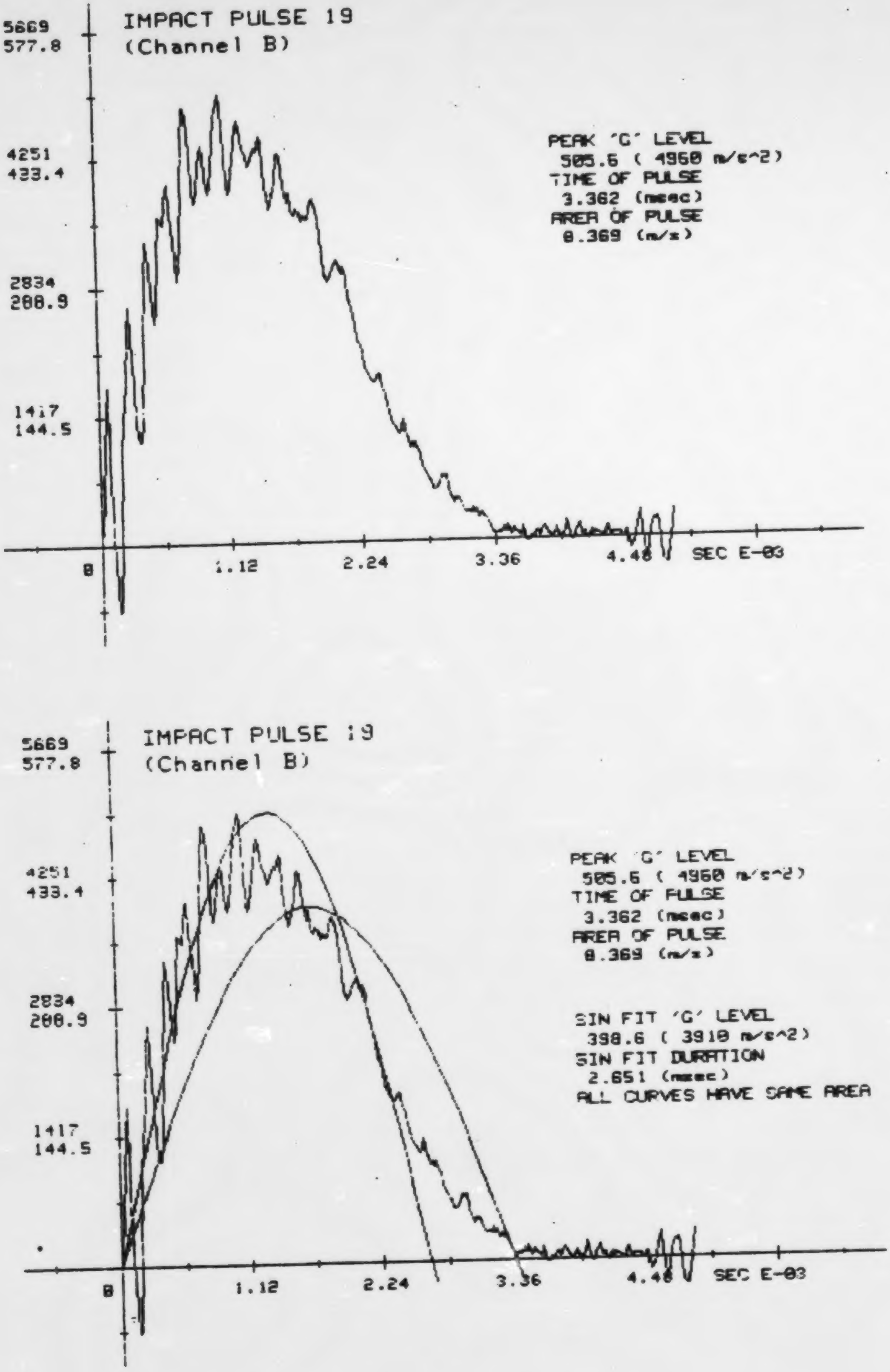


FIGURE 17 - Typical acceleration-time curve as processed by the computer.

10,000 Hz. The light bulb sockets were epoxied into the fixture to ensure as solid a mounting as possible. The fixture was then bolted firmly to the table with a gasket and thin film of oil to prevent ringing. Differences between the impact table and fixture were still measureable at high g levels but were much more acceptable. Finally, the impact machine itself was originally designed to provide a maximum total energy of approximately 260 newton-meters, allowing for a maximum pulse of approximately 1000g for one millisecond. After testing and examination of actual bulbs recovered from aircraft crashes, it was quite evident that these design parameters would have to be increased. Therefore shock cords were attached to the drop table to produce impact pulses of up to 4000 g over 0.7 milliseconds which caused damage similar to that found in type 327 bulbs recovered from actual aircraft crashes. Impact machine maintenance, however, became costly in terms of time as breakdowns due to these high g levels became frequent. Once the above mentioned problems were corrected, the testing of over 400 GE-327 light bulbs went relatively smoothly.

6.5 Due to the high g level short duration pulses required to cause significant damage to the light bulbs, machine restrictions and time did not permit the trapezoidal wave impact tests which are standard for obtaining damage boundary curves in compliance with ASTM guideline D3332-77. Although this standard test method is orientated for fragility assessment in the packaging and transportation industry, the theory applies just the same. Different pulse shapes will generate different damage boundary curves. Most damage boundary curves utilize a trapezoid wave to yield a damage boundary curve because much fewer data points are required to determine the boundary. A sample trapezoidal wave and sine wave generated damage boundary curve is shown in Figure 18. Trapezoid wave impact testing, at the high g levels and short durations required, would have meant a redesign of the impact machine, which was beyond the scope of this project.

6.6 Prior to each impact test, the steady state cold resistance of the filament was measured and bussed to the computer. After impact, the steady state cold resistance was again measured. Resistance changes did occur when the filament

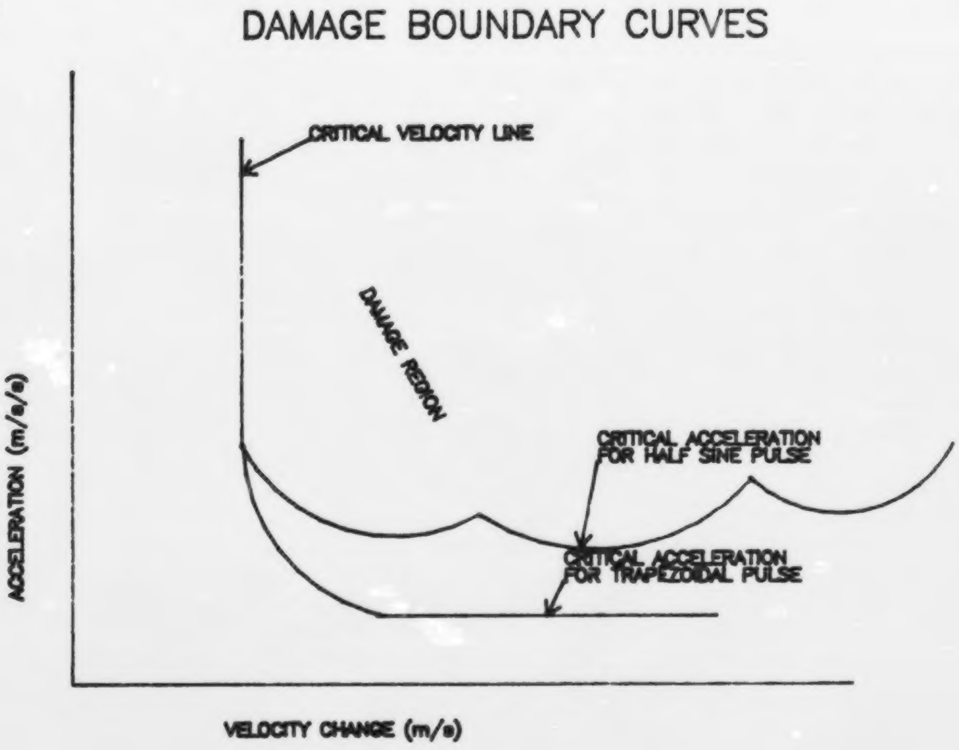


FIGURE 18 - Sample damage boundary curves using trapezoidal and sine wave impacts.

deformed under impact and adjacent coils shorted together, which usually resulted in a resistance drop. In general, the greater the impact, the greater the resistance drop. These measurements were taken during testing in order to determine the possibility of the occurrance of a resistance change which was in some manner proportional to the severity of impact; however, the resistance measurements did not always reflect this.

6.7 The light bulb mounting fixture designed for impact testing housed four type GE-327 light bulbs. The bulbs were tested in the horizontal position with the plane of the support posts in line with the impact. This orientation provided for the maximum response. Any other orientation would require higher g levels to cause damage. Filament damage was categorized as general deformation, local deformation, and/or fracture. General deformation was defined as general distortion of the filament while the individual turns remained tightly and regularly coiled. Local deformation was defined as uncoiling or expansion and contraction of the filament coils (stretch).

6.8 A pictorial summary of the results of the impact tests performed is shown in Figures 19 through 32. Tests were done at both 28 volts d.c. and 0 volts with peak deceleration levels up to 4000 g. Impact profiles and pertinent test data for these tests can be found in Appendix "A".

6.9 The elastomer impact pads used limited the time span of impact pulses to a minimum of approximately 0.7 msec half-sine. This corresponded to a pulse frequency of 714 Hz, which was below the major natural frequencies of the GE-327 light bulb system. In order to cause excitation of the system, the impact pulse would have to contain high frequency components (1300-1500 Hz) or have a fundamental pulse duration of $(1/1300)/2 = 0.4$ milliseconds or less. A half-sine pulse of 0.4 msec duration or shorter would cause resonance of the light bulb system and result in substantially more damage at lower g levels. Since the impact machine used for testing was not designed for producing such short duration impacts, some tests were carried out using a hammer to directly impact a fixture.

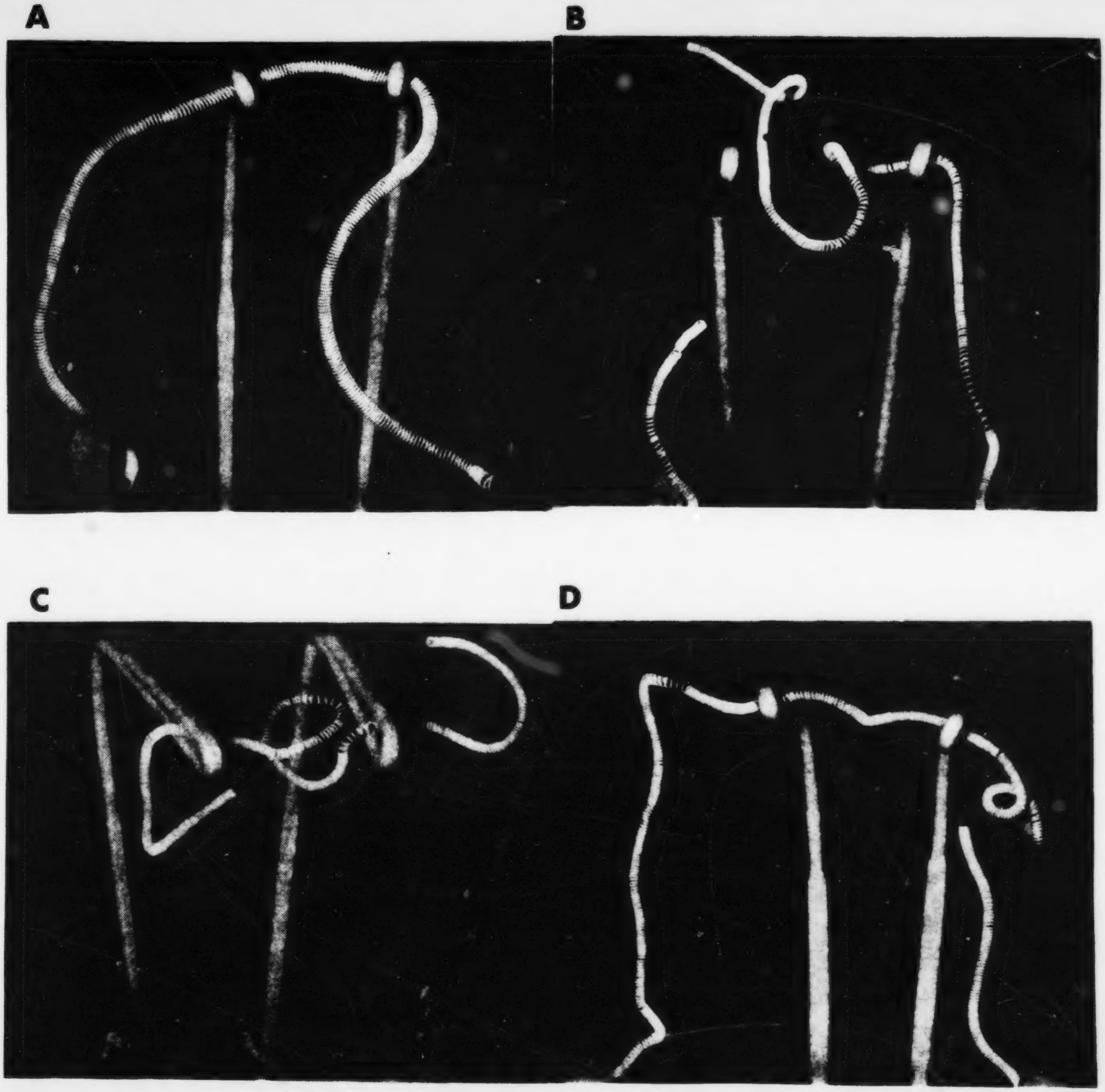


FIGURE 19 - TEST 23; ALL FILAMENTS IMPACTED AT 1000G FOR 1.5 MSEC. AT 28 VOLTS
A) AGED 0 HOURS
B) AGED 48 HOURS (FILAMENT FRACTURED UPON REMOVAL OF GLASS ENVELOPE)
C) AGED 85 HOURS
D) AGED 144 HOURS (FILAMENT FRACTURED UPON REMOVAL OF GLASS ENVELOPE)

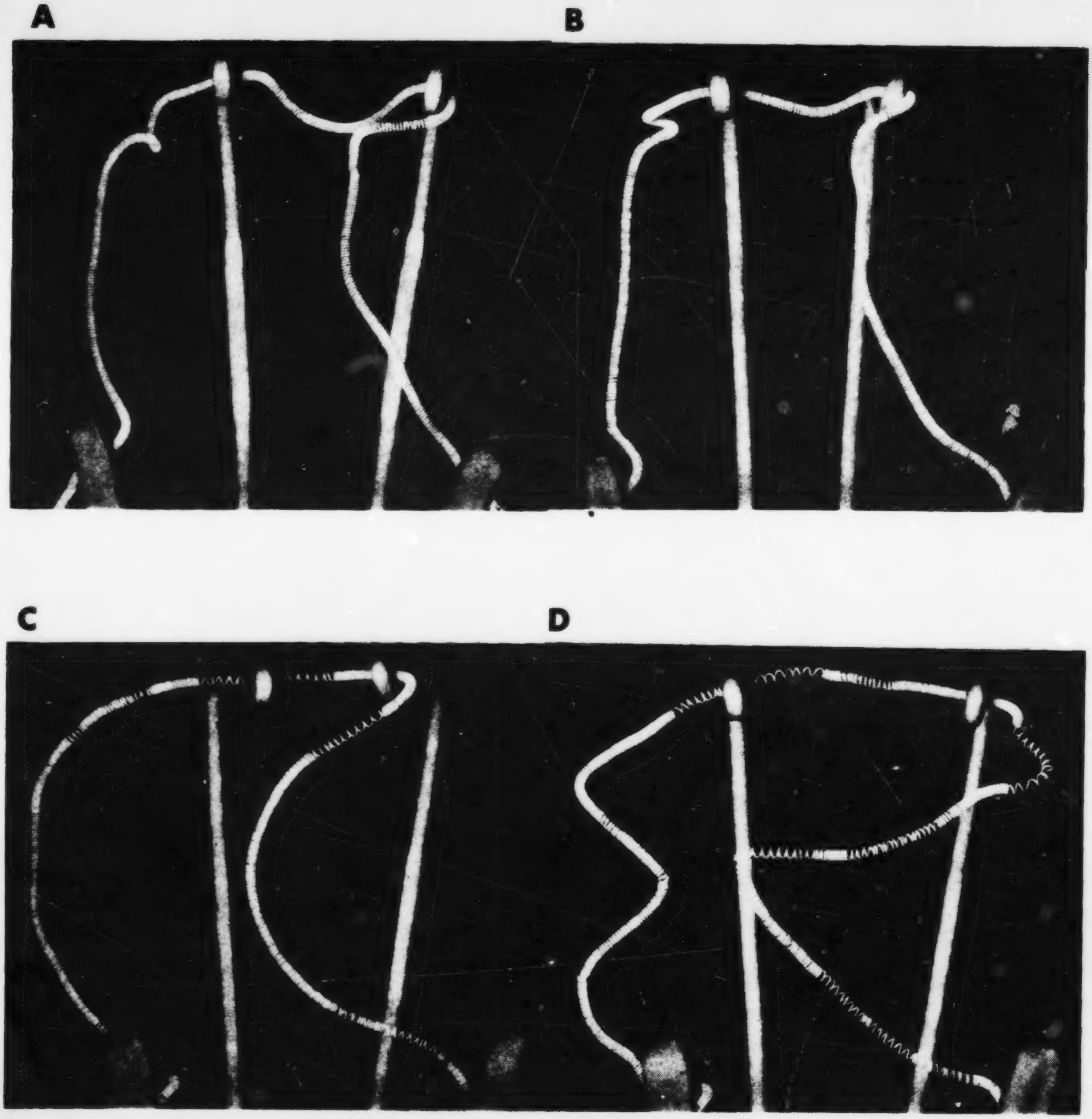


FIGURE 20 - TEST 26; ALL FILAMENTS IMPACTED AT 1400G FOR 1.5 MSEC AT 28 VOLTS
A) AGED 210 HOURS
B) AGED 250 HOURS
C) AGED 350 HOURS
D) AGED 506 HOURS

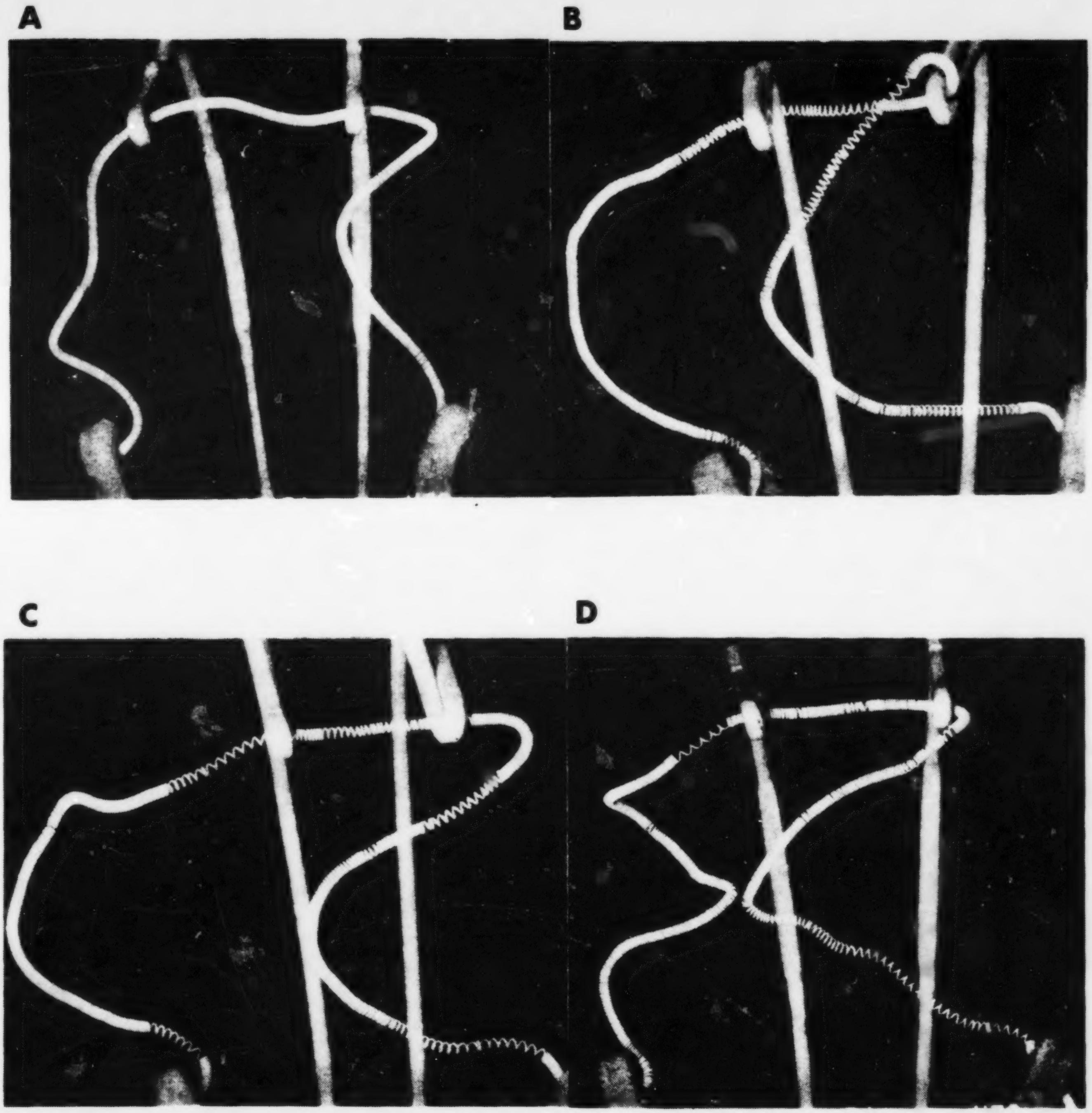


FIGURE 21 - TEST 37; ALL FILAMENTS IMPACTED AT 1519G for 1.5 MSEC AT 28 VOLTS

A) AGED 0 HOURS
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

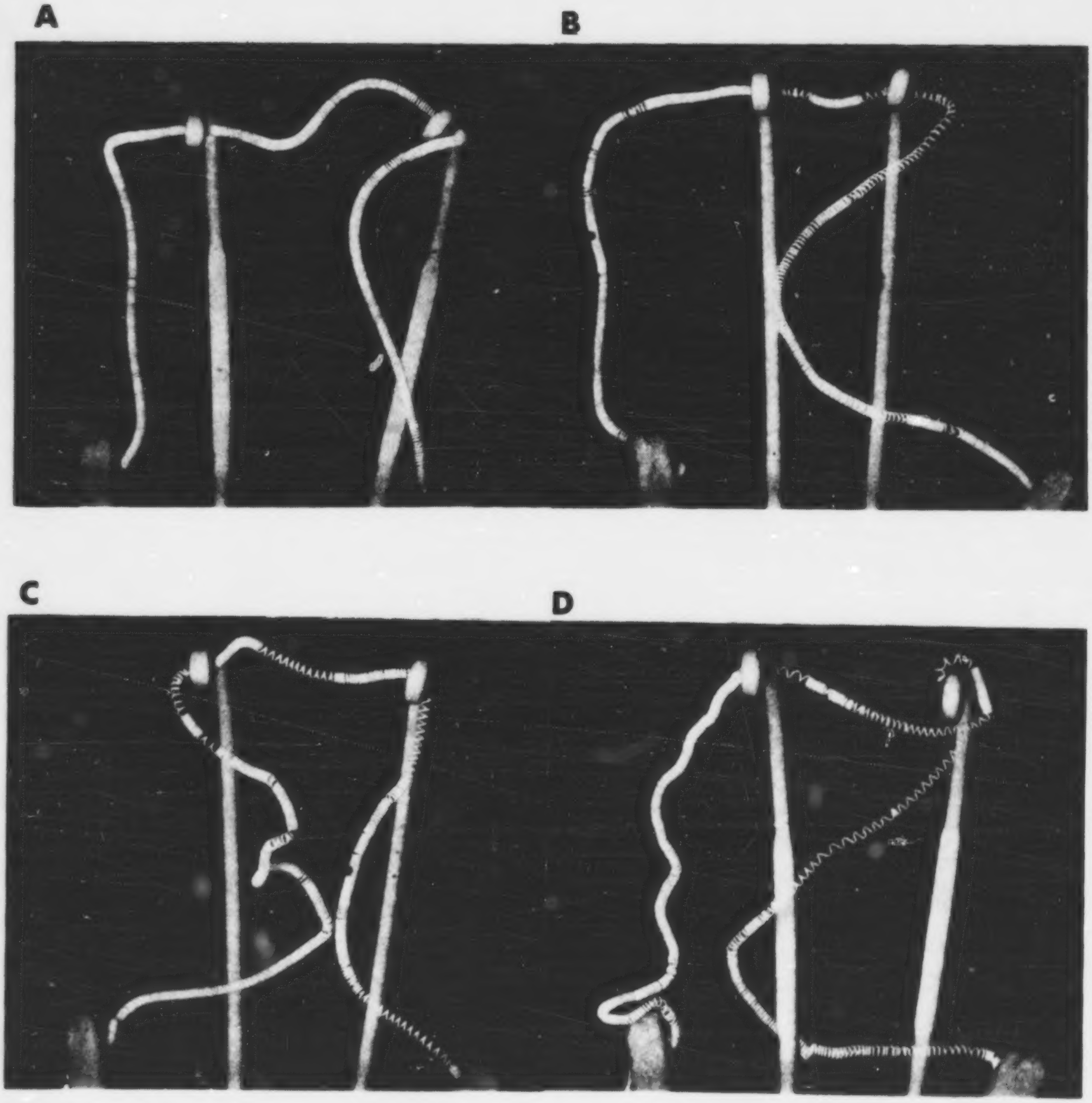


FIGURE 22 - TEST 54; ALL FILAMENTS IMPACTED AT 2200 G FOR 0.9
MSEC AT 28 VOLTS
A) AGED 0 HOURS
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

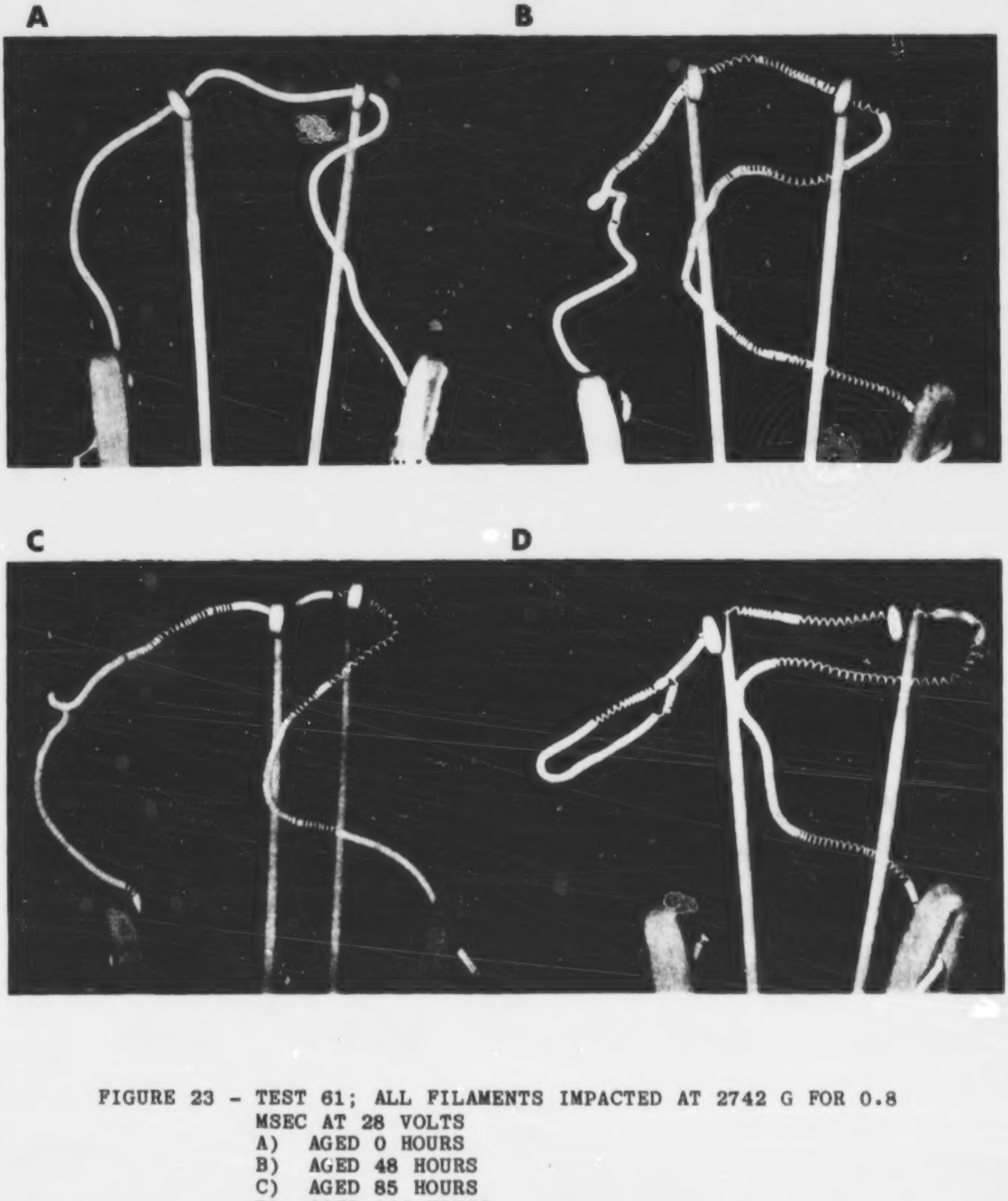


FIGURE 23 - TEST 61; ALL FILAMENTS IMPACTED AT 2742 G FOR 0.8 MSEC AT 28 VOLTS
A) AGED 0 HOURS
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

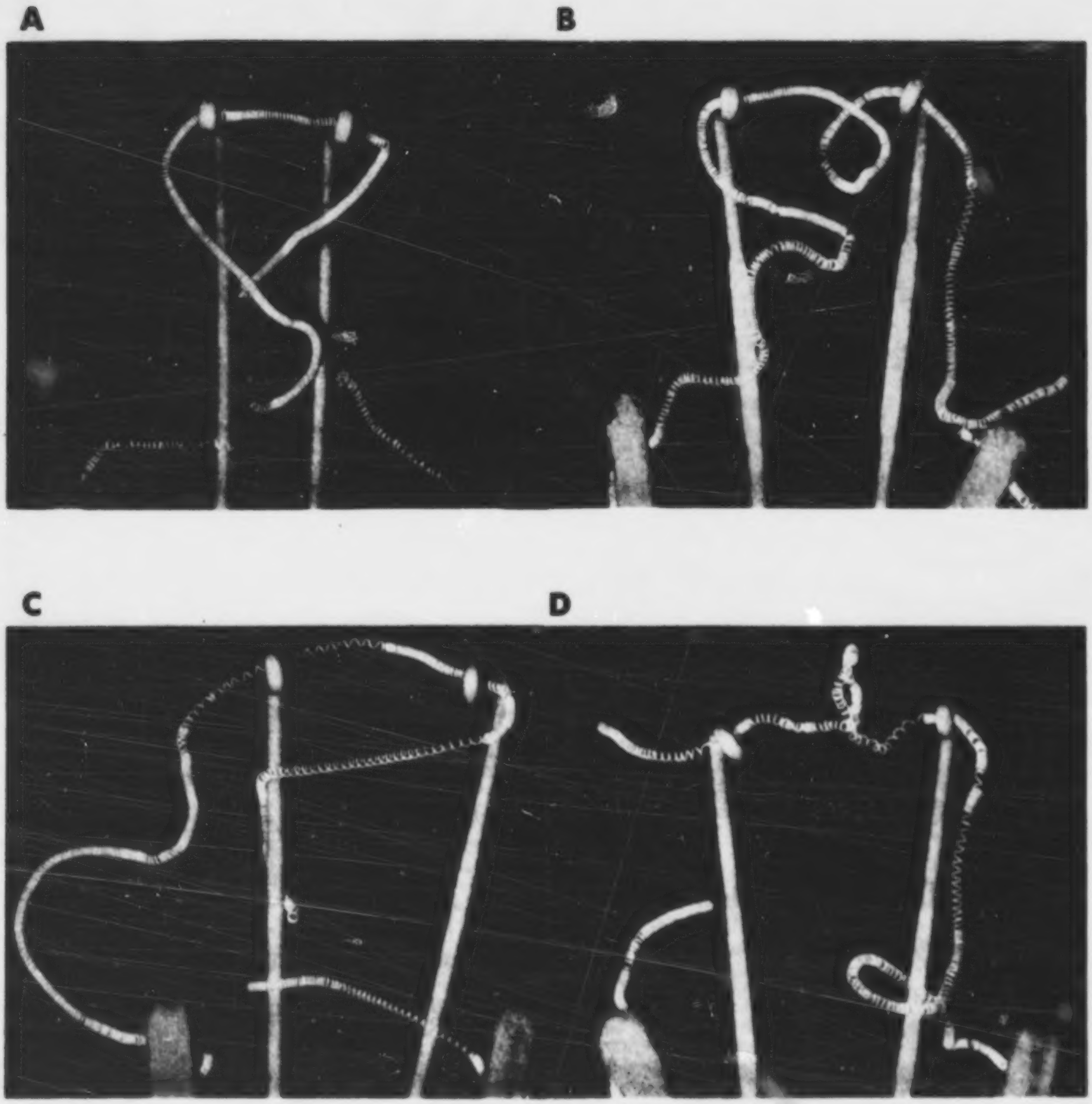


FIGURE 24 - TEST 88; ALL FILAMENTS IMPACTED AT 3089 G FOR 0.9 MSEC AT 28 VOLTS
A) AGED 0 HOURS
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

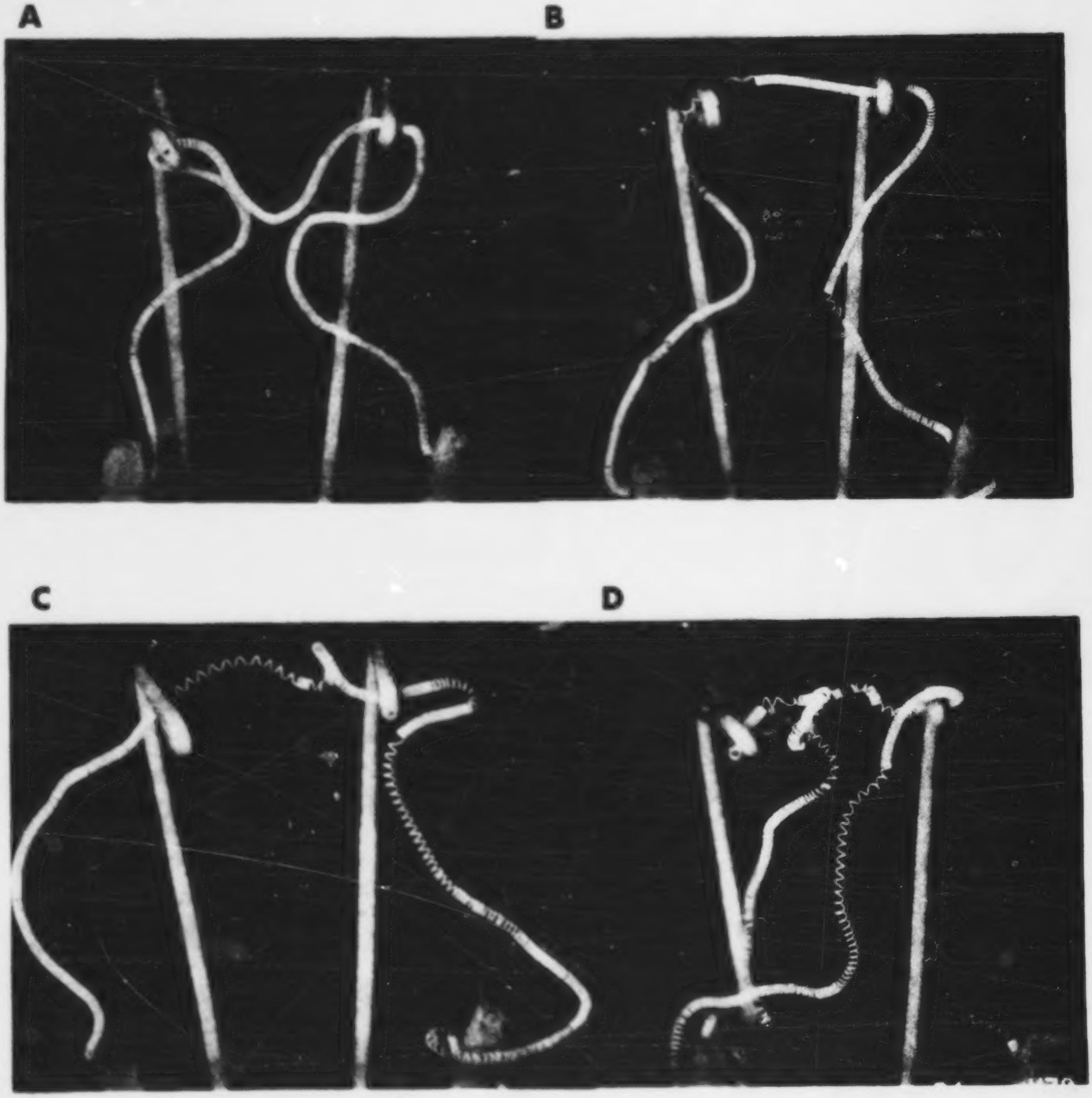


FIGURE 25 - TEST 64; ALL FILAMENTS IMPACTED AT 3507 G FOR 1.0 MSEC AT 28 VOLTS
A) AGED 0 HOURS
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

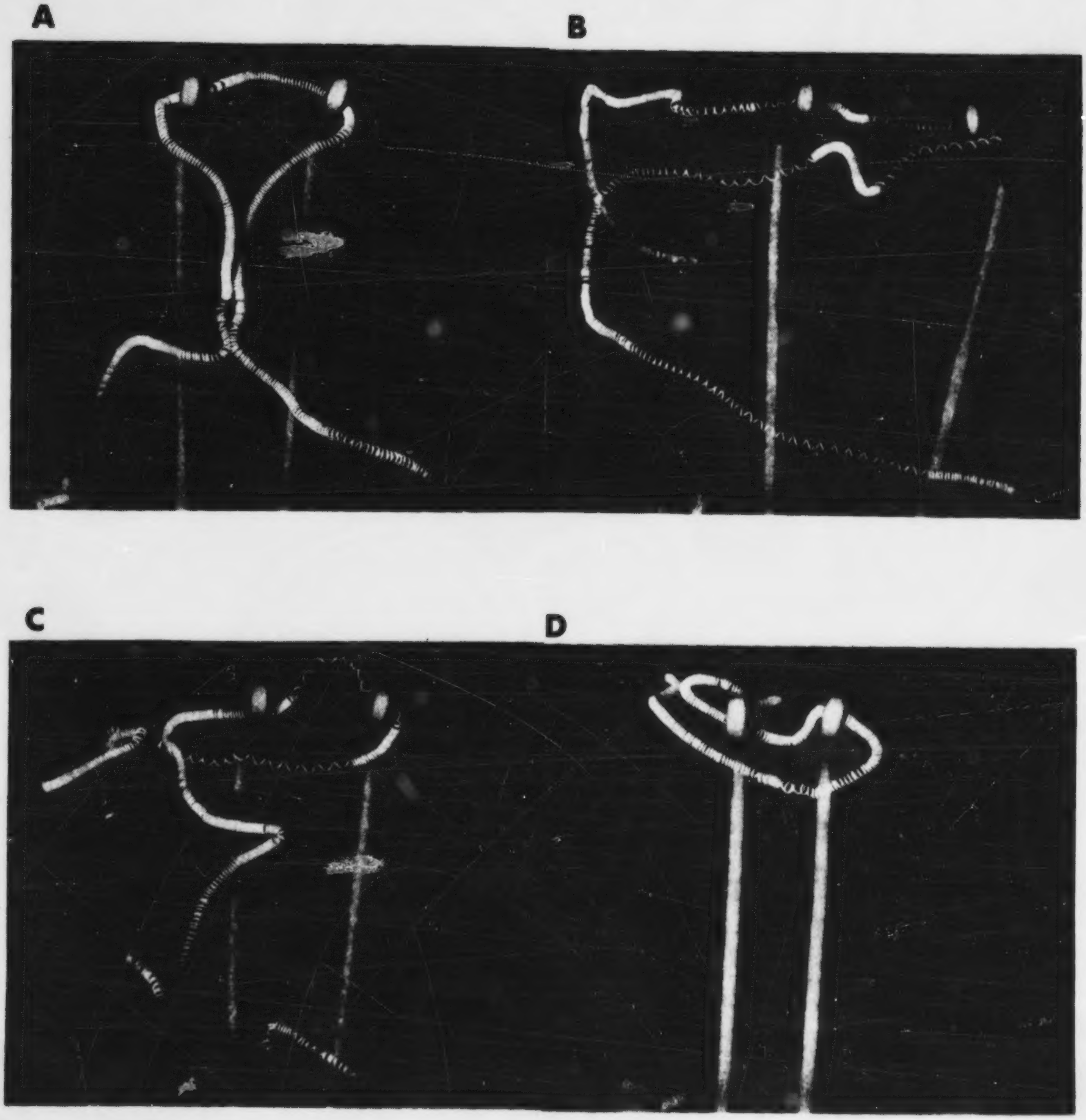


FIGURE 26 - TEST 100; ALL FILAMENTS IMPACTED AT 4006 G FOR 0.9 MSEC AT 28 VOLTS

A) AGED 0 HOURS
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

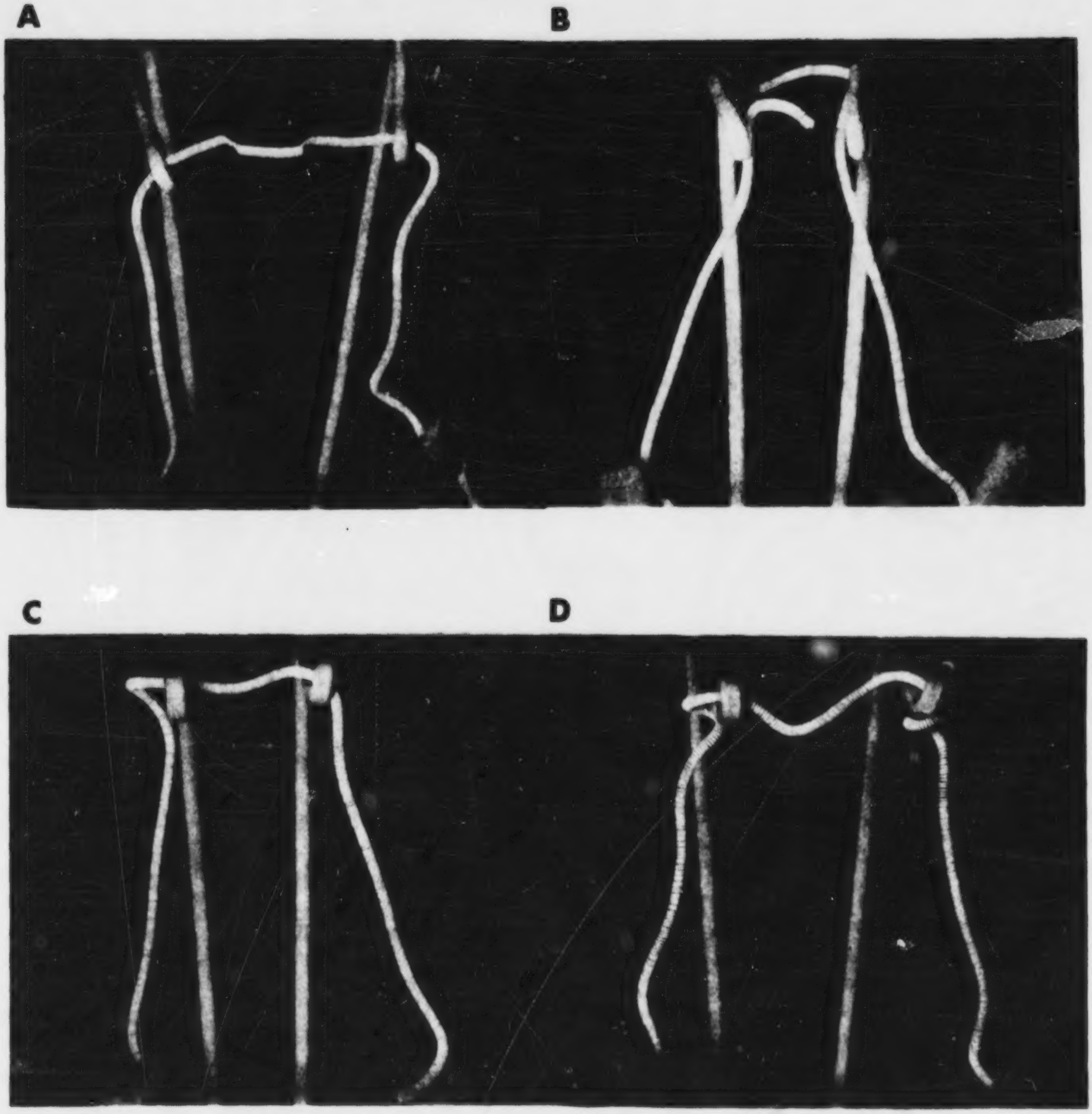


FIGURE 27 - TEST 38; ALL FILAMENTS IMPACTED AT 1570 G FOR 1.6 MSEC AT 0 VOLTS

A) AGED 0 HOURS (ABNORMALITY IN FILAMENT ATTRIBUTED TO MANUFACTURING PROCESS)
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

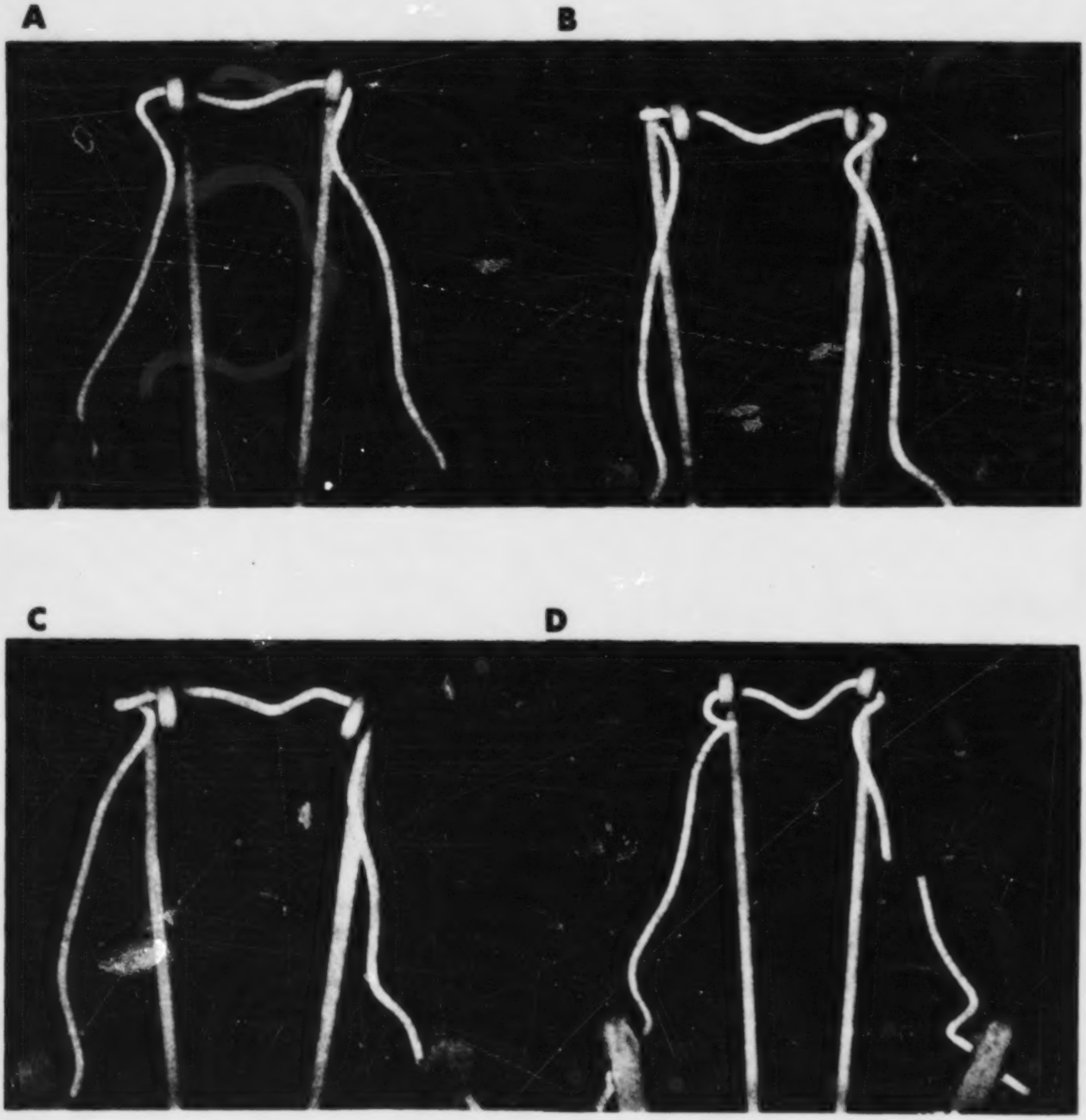


FIGURE 28 - TEST 31; ALL FILAMENTS IMPACTED AT 1397 G FOR 1.3 MSEC AT 0 VOLTS
A) AGED 210 HOURS
B) AGED 250 HOURS
C) AGED 350 HOURS
D) AGED 506 HOURS

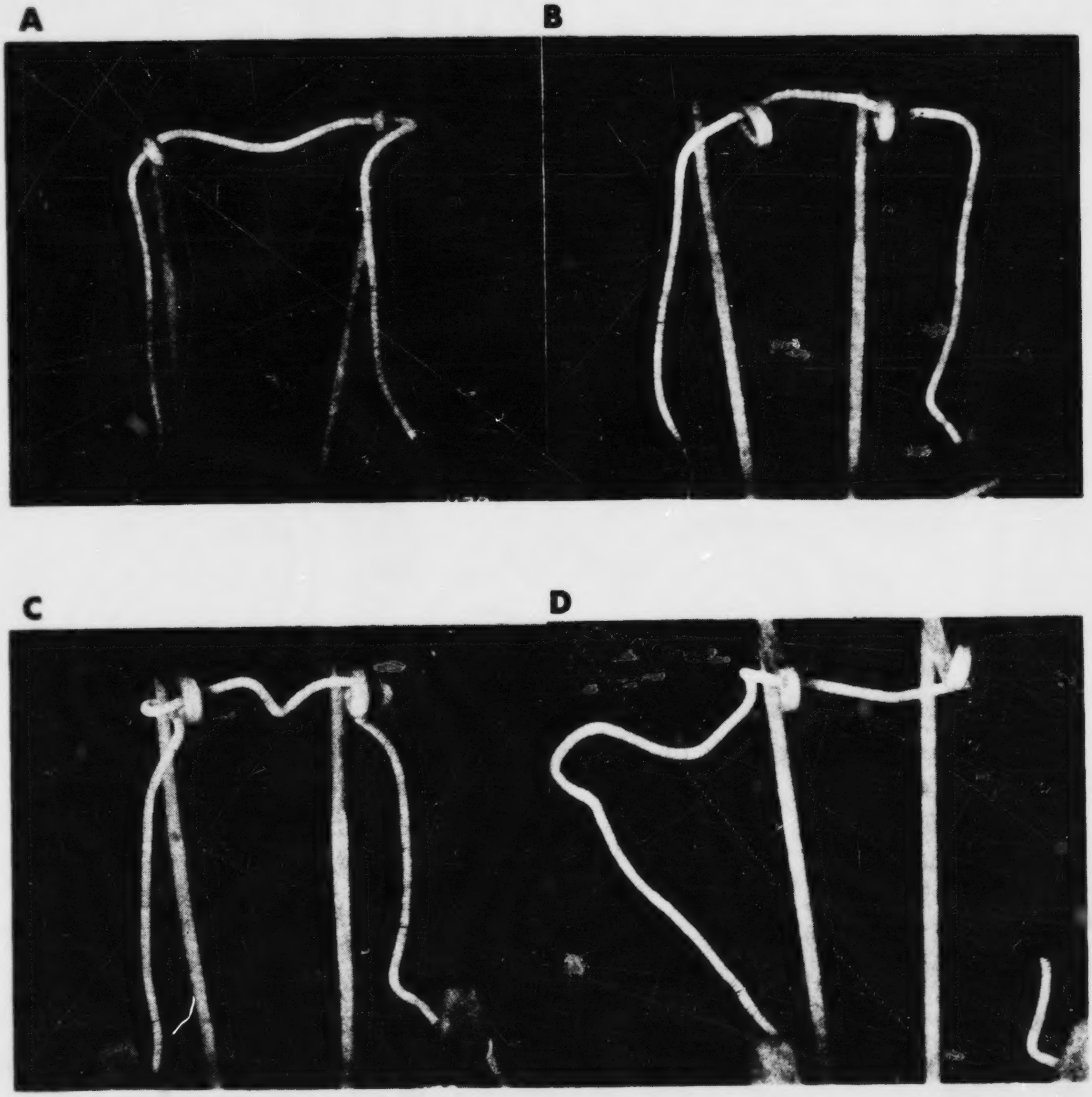


FIGURE 29 - TEST 66; ALL FILAMENTS IMPACTED AT 3262 G FOR 1.0 MSEC AT 0 VOLTS
A) AGED 0 HOURS
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

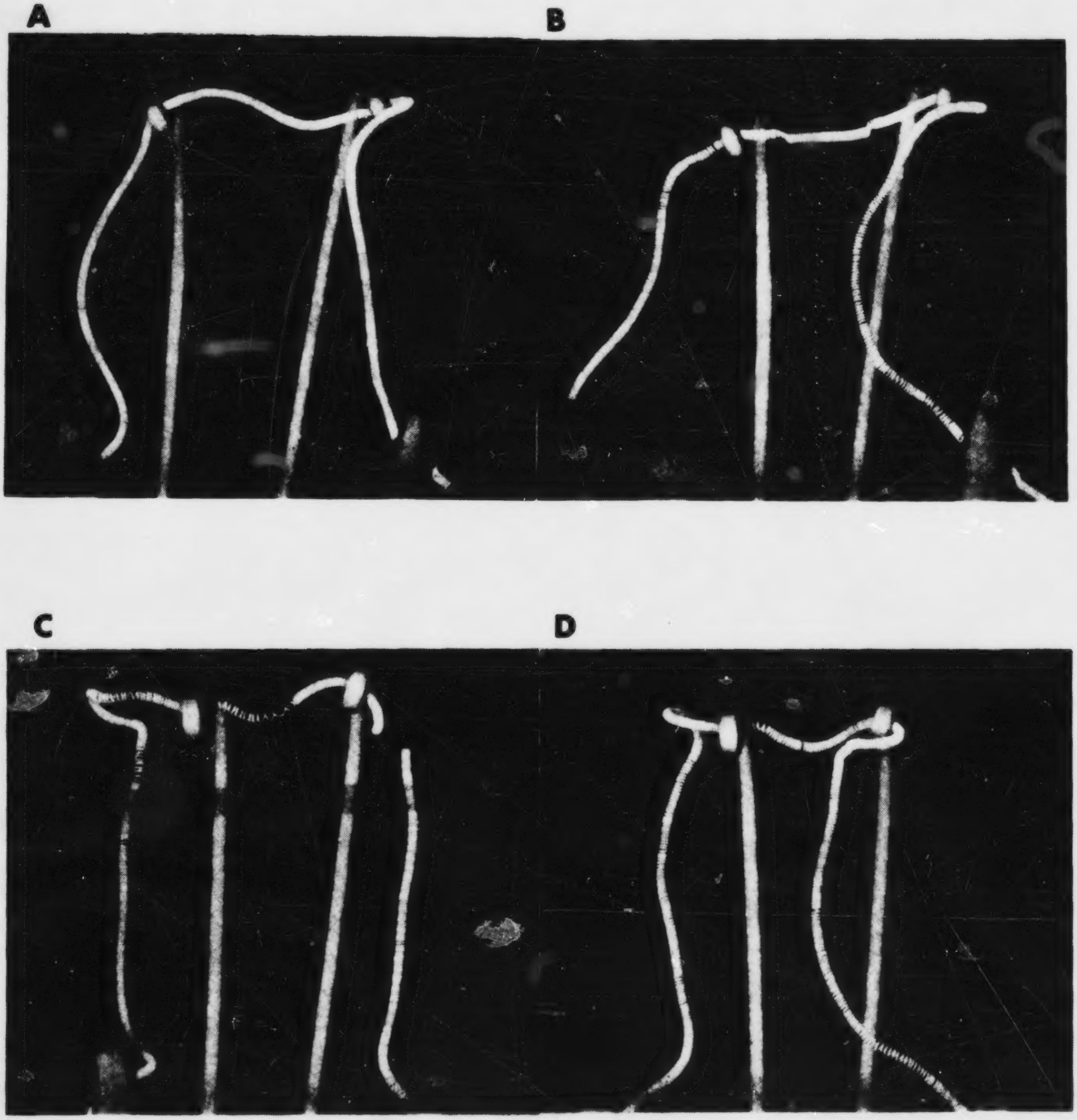


FIGURE 30 - TEST 106; ALL FILAMENTS IMPACTED AT 4016 G FOR 0.7 MSEC AT 0 VOLTS
A) AGED 0 HOURS
B) AGED 48 HOURS
C) AGED 85 HOURS
D) AGED 144 HOURS

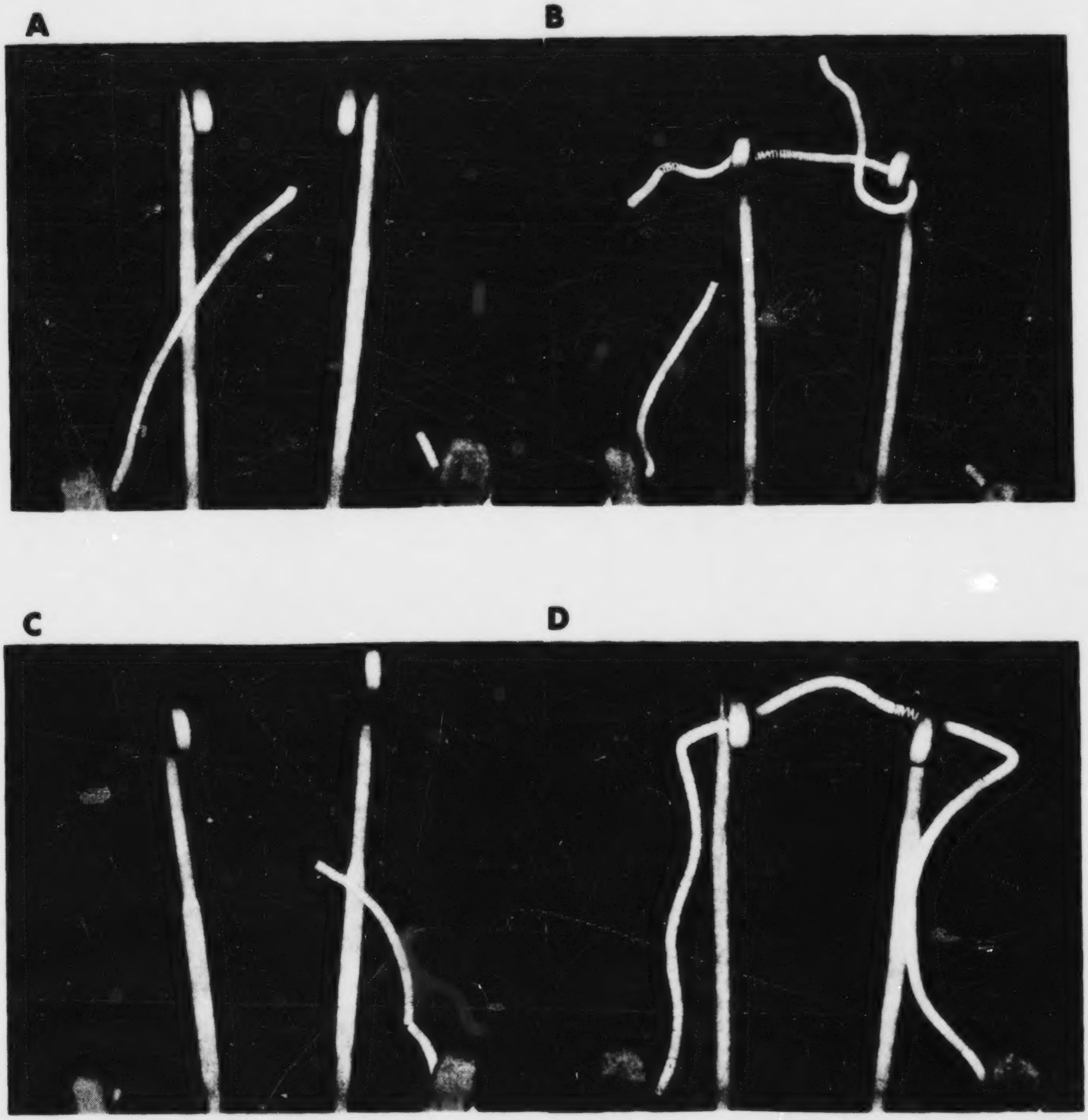


FIGURE 31 - TEST 109; ALL FILAMENTS IMPACTED AT 3945 G FOR 0.7 MSEC AT 0 VOLTS
A) AGED 210 HOURS
B) AGED 210 HOURS
C) AGED 250 HOURS
D) AGED 250 HOURS

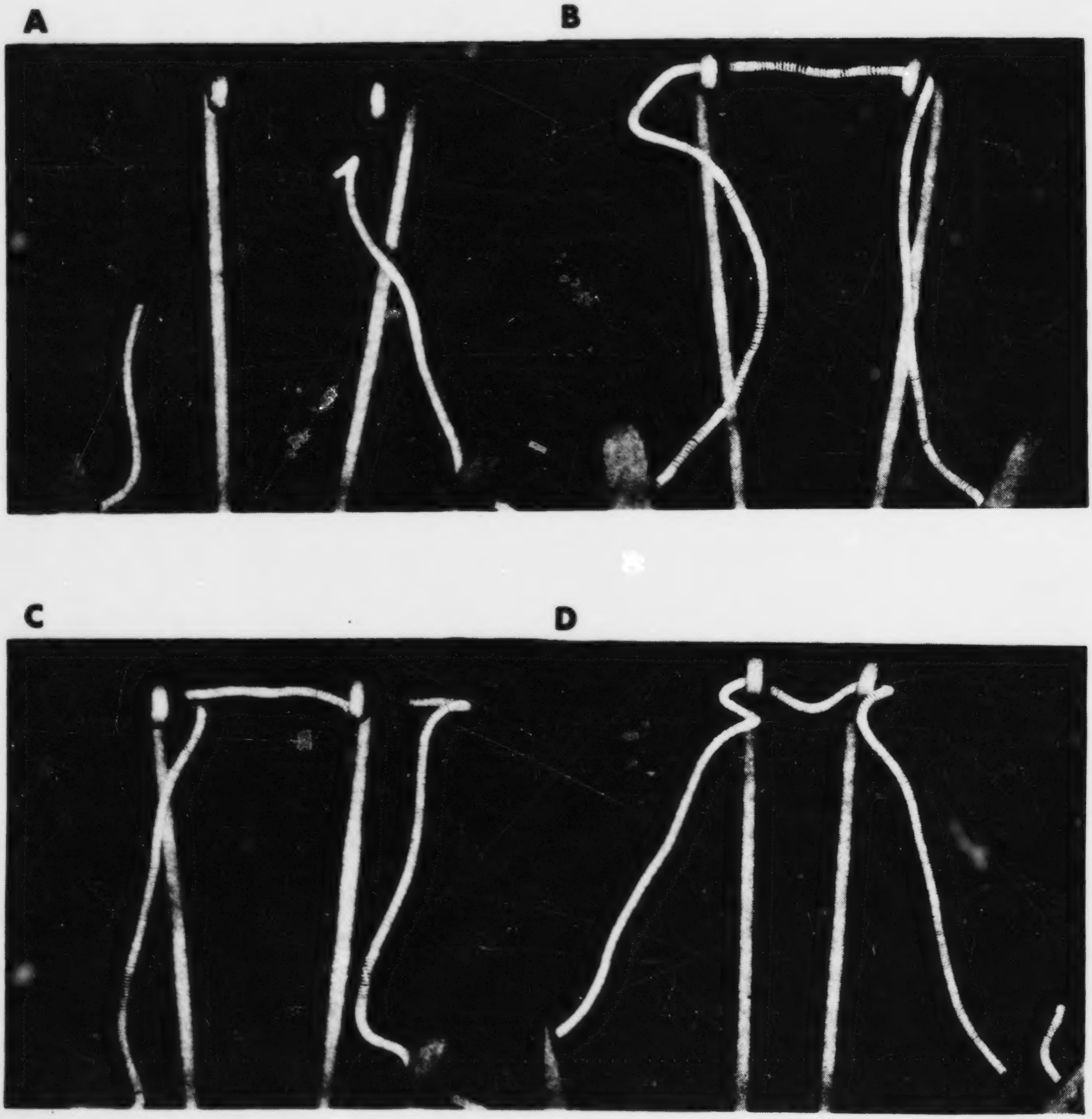


FIGURE 32 - TEST 108; ALL FILAMENTS IMPACTED AT 4016G FOR 0.7 MSEC AT 0 VOLTS
A) AGED 210 HOURS
B) AGED 210 HOURS
C) AGED 250 HOURS
D) AGED 250 HOURS

This produced an impact of short duration which in turn excited the support posts of the light bulb at their natural frequency. Some of these tests were captured on high speed film and the resonant support post action was clearly seen. Due to the complex resonances of the fixture used for these tests, the impact pulses recorded were not considered entirely representative of the impact seen by the light bulbs, as the vibrations varied considerably from point to point on the fixture. Figure 33 shows the result of testing of bulbs in both hot and cold conditions, subjected to an impact of short duration such that the support posts attained resonance. Notice that a small amount of both local and general deformation is evident in the cold impacted bulb aged 0 hours(33C).

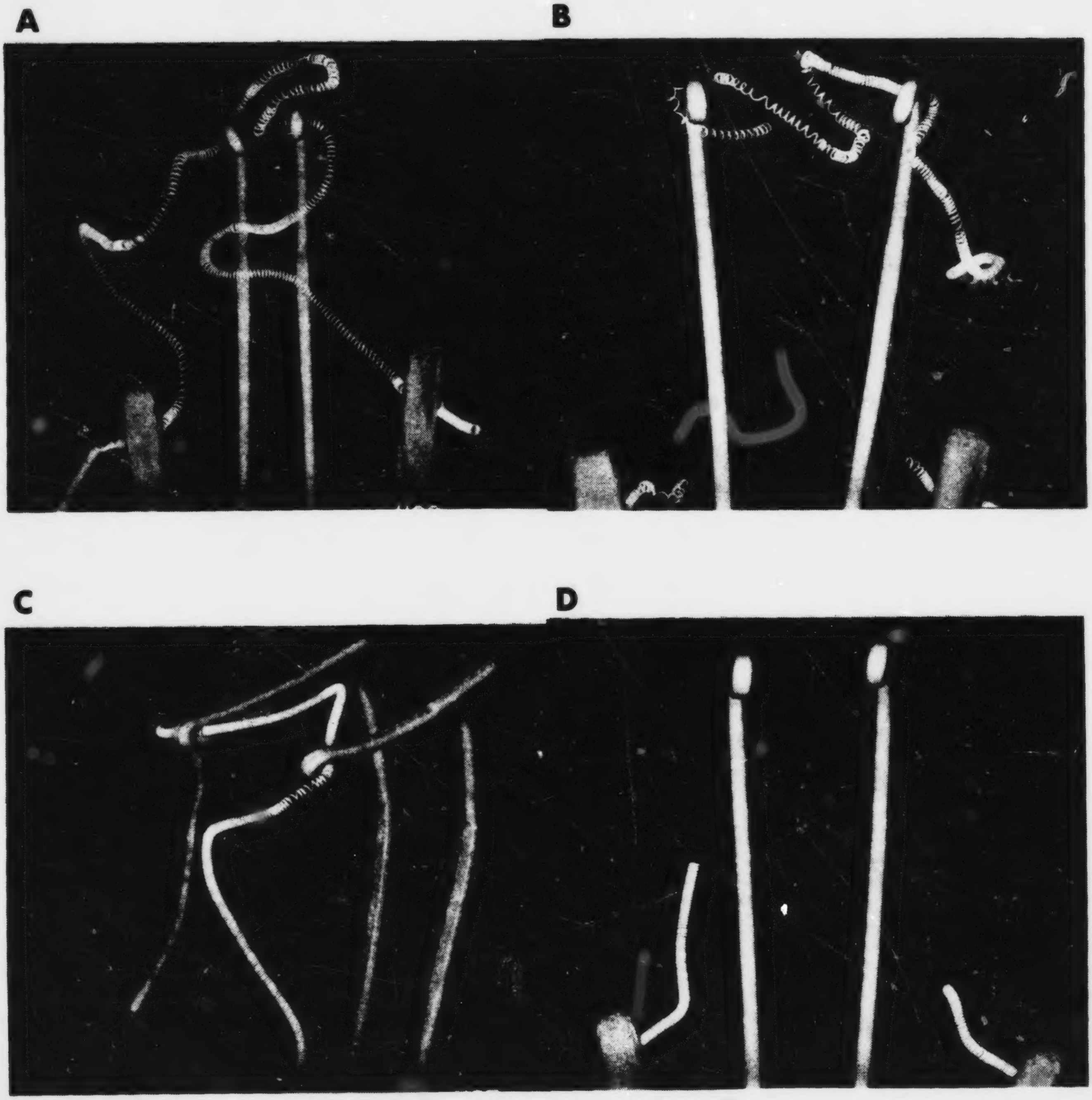


FIGURE 33 - BULBS SUBJECTED TO IMPACT IN THE RESONANCE RANGE.
A) TEST 8; AGED 0 HOURS; IMPACTED AT 4000G FOR .3 MSEC AT 28 VOLTS
B) TEST 120; AGE 210 HOUR; IMPACTED AT 4000G FOR 0.4 MSEC AT 28 VOLTS
C) TEST 12; AGED 0 HOURS; IMPACTED AT 4000G FOR .3 MSEC AT 0 VOLTS
D) TEST 121, AGED 210 HOURS; IMPACTED AT 3700 G FOR 0.4 MSEC AT 0 VOLTS

7.0 IMPACT TEST RESULTS

7.1 A review of the impact tests depicted in Figures 19 to 33 revealed that the most important factors to be considered in light bulb filament analysis are filament age and severity and type of impact (resonance). As discovered in the resonance vibration tests, the older the filament, the more susceptible it is to impact damage for both hot and cold filaments. Figure 34 shows the relationship between filament age and g level required to cause damage (assuming no resonance). New bulbs can withstand a substantial impact deceleration level, especially when cold. The large shift between the hot and cold lines of Figure 34 illustrates that cold bulbs can generally withstand greater impacts, especially for the first couple of hundred of hours burning time. Light bulb manufacturers suggest that cold filaments are more susceptible to damage than hot filaments. This statement becomes true as the filament ages and the notching develops to a point where the filament behaves in an extremely brittle and fragile manner under cold conditions due to the dramatic reduction in local cross-sectional area. Testing of bulbs aged more than 300 hours was prohibitively difficult because their filaments tended to fracture due to handling, before tests could be conducted. Tests did show, however, that new cold bulbs could withstand relatively high impacts while new hot bulbs would stretch and deform at those impact levels. It is important to remember that if the impacts were of short enough duration to have caused resonance of the bulb's internal components (ie. support posts), the g levels required for damage for both hot and cold bulbs would be lower still.

7.2 New hot filaments exhibited no local deformation except in the higher g ranges (approximately 3000 g's). Typically, new hot filaments only deformed while remaining tightly coiled. Aged hot filaments showed increased local deformation which eventually led to failure (fracture). Of the cold bulbs tested on the impact machine, none showed significant evidence of local deformation. High g level tests of new cold bulbs resulted in some general deformation that was not directly distinguishable from general deformation produced

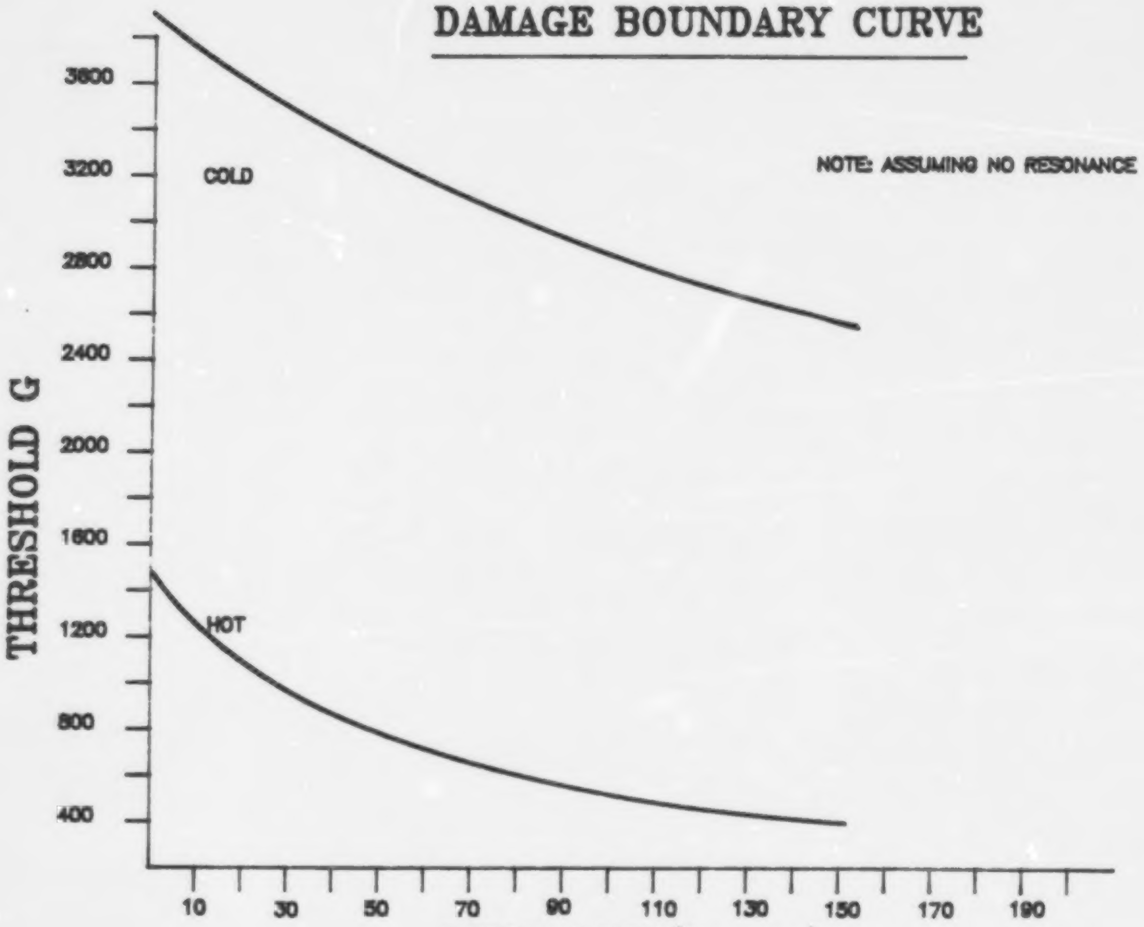


FIGURE 34 - Damage boundary curves for hot and cold GE-327 bulbs.

from hot bulbs tested at low g levels. With increasing age, cold bulbs tended to fracture without showing signs of general or local deformation. Local filament deformation occurred in a cold bulb when resonance was achieved at high g level, and the bulb was relatively new. This local deformation was likely the result of the support posts 'whipping' the filament around during impact and was typically confined to small areas. Cold local stretch was not observed in older bulbs and is not expected to occur for these types of bulbs except possibly in areas where filaments have not recrystallized (heat sink areas) or where the filament is less notched. This cold local deformation at high impacts was not directly distinguishable from hot local deformation due to low g impacts. This demonstrates the necessity of examining a group of light bulbs known to have been subjected to essentially the same impact forces, performing a comparative analysis, and acquiring some knowledge of the local impact forces involved in the crash.

8.0 FRACTURE ANALYSIS

8.1 Fracture surface characteristics are largely a function of filament temperature and microstructure. Recrystallization and the development of d.c. notching causes the microstructure to continually change, not necessarily in a uniform manner. Fractures generally occurred across the grain boundaries that separate large crystals formed in the aging process and through single crystals at notching points where the cross-sectional area was greatly reduced. Because of the non-uniform microstructure development, it is not uncommon to observe different types of fractures in the same light bulb. Figure 35 shows the grain boundary structure, and the subsequent cold intergranular fracture that occurred. Figure 36 shows a filament impacted cold at 1376 g over 1.5 milliseconds and the intergranular fracture surface typical of a cold failure. Also, notice in this Figure that the general deformation is simply due to the aging process and is not impact induced damage. Other cold fracture surfaces that were discovered are shown in Figures 37 and 38. The smooth fracture surfaces are a result of the advanced stages of aging. The fractures may have occurred across one or two grain boundaries or occurred transgranularly. Notice that the fracture edges remain relatively sharp even though the advanced aging gives a 'smooth' appearance.

8.2 When a hot filament is subjected to a severe impact, the ductile state of the filament allows it to deform and uncoil without necessarily breaking. As the hot filament stretches, the probability of the filament crossing together and shorting itself out increases. Generally, the failure mode during a hot impact is burn-out due to this shorting. The fracture does not necessarily occur at the point of contact, but usually somewhere in the length of filament which was short circuited. High-speed cinematography has revealed that when a filament touched together in such circumstances, a large flash of light was generally produced at the contact point and the entire length of filament that was short circuited became brighter. Figure 39 shows a hot filament (aged 210 hours) that was subjected to a 1672 g half-sine impact over 1.4 msec. Fracture did not occur until a few seconds after impact, when the bulb was observed to glow brighter than normal and then burn-out.

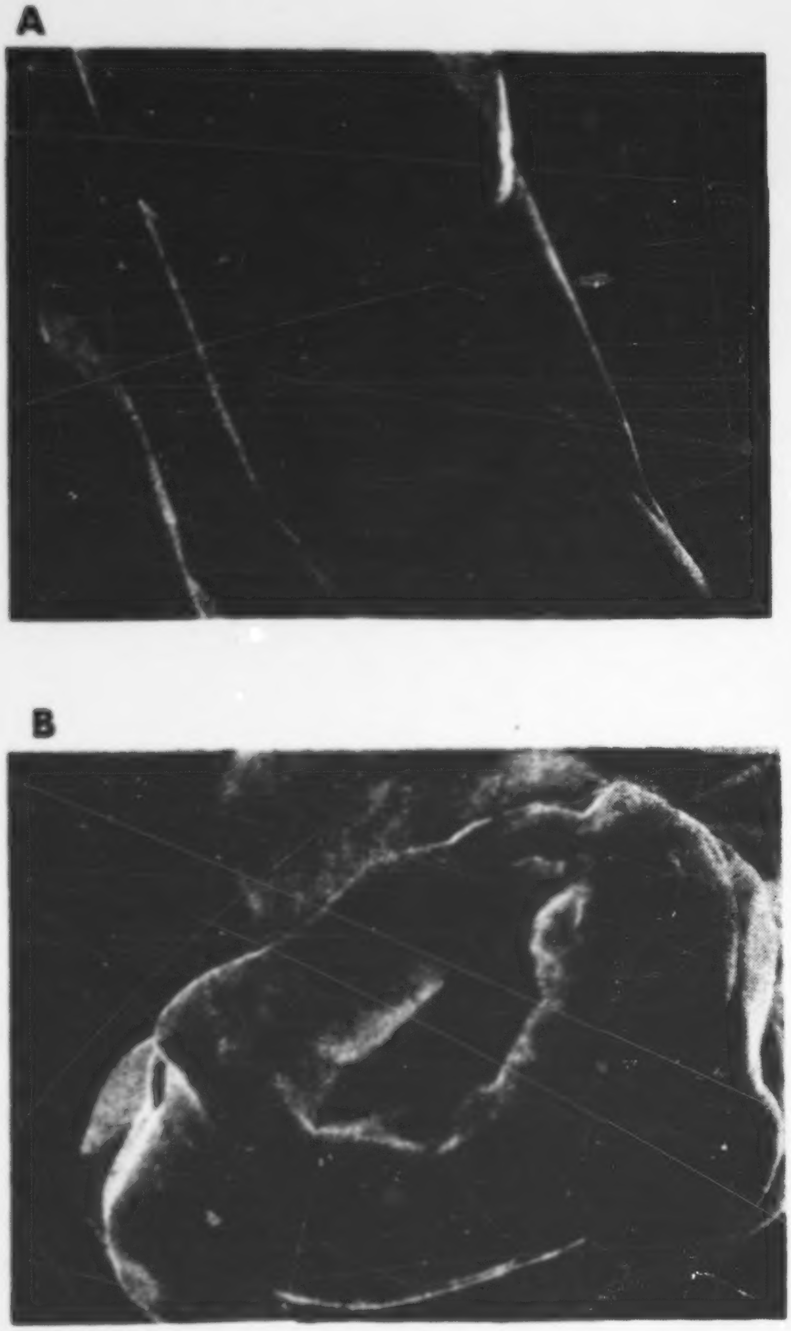


FIGURE 35 - GRAIN STRUCTURE THAT HAS DEVELOPED OVER 506 HOURS OF BURNING (A) AND 'COLD' INTERGRANULAR FRACTURE SURFACE (B).

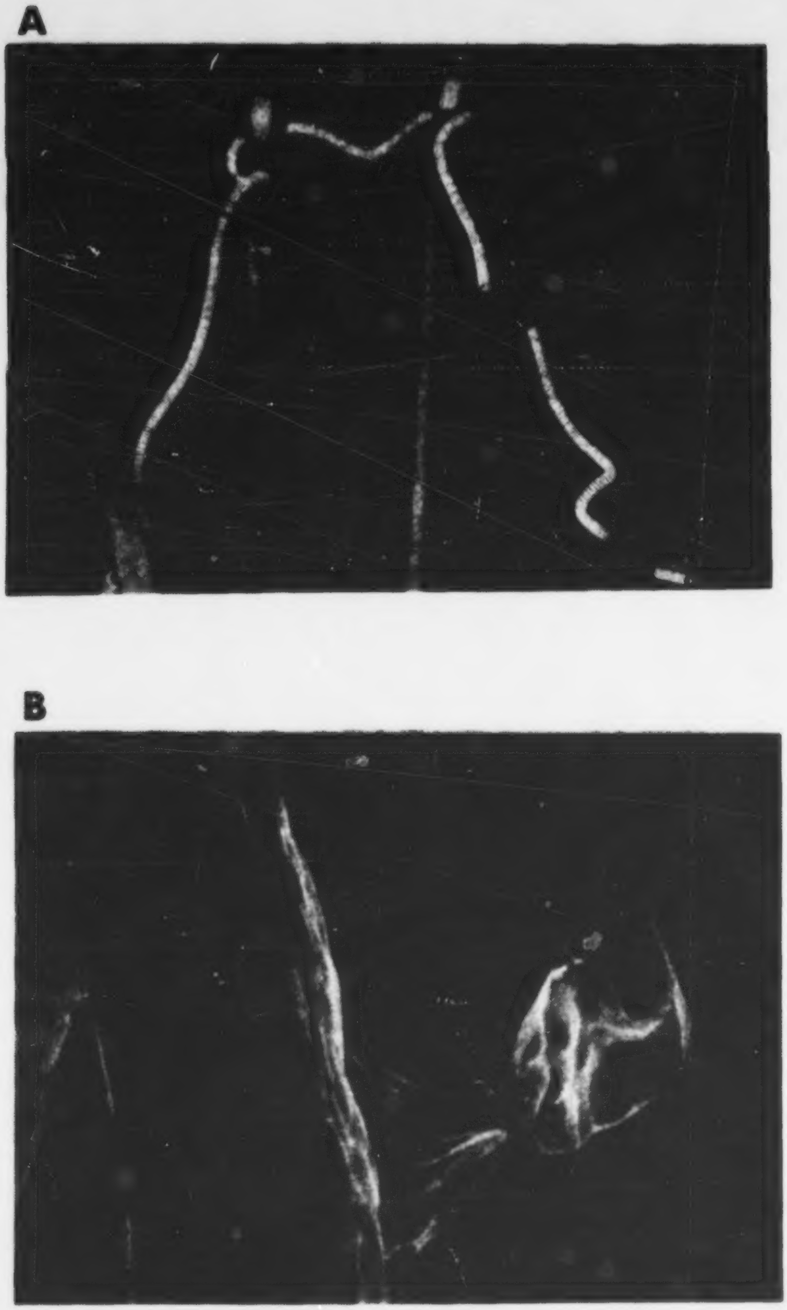


FIGURE 36 - COLD FILAMENT SUBJECTED TO 1397 G'S OVER 1.5 MSEC (A) AND THE INTERGRANULAR FRACTURE SURFACE THAT RESULTED (B) TYPICAL OF A 'COLD' FRACTURE.

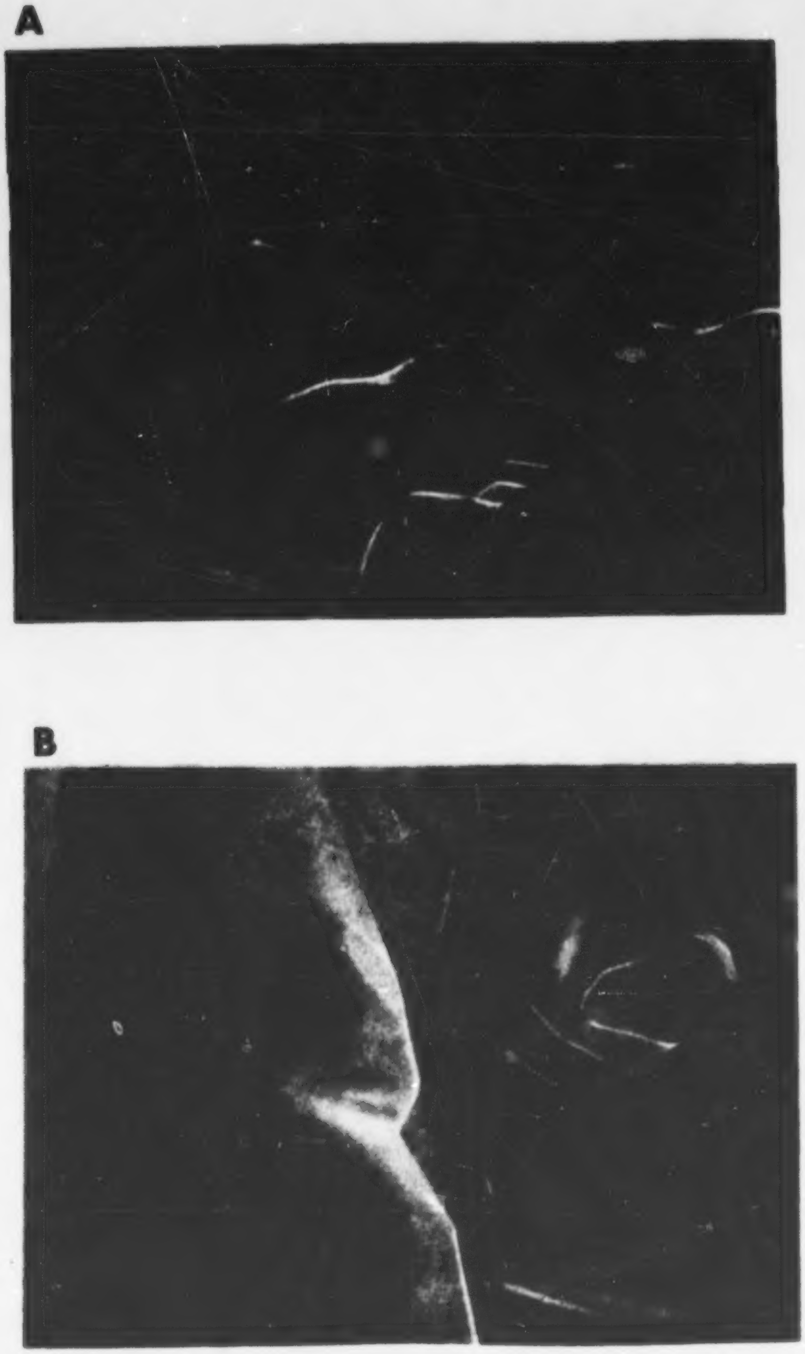


FIGURE 37 - COLD FRACTURE SURFACES FOUND IN A SEVERELY NOTCHED (AGED) SECTION OF FILAMENT. A = 3000X, B = 2500X

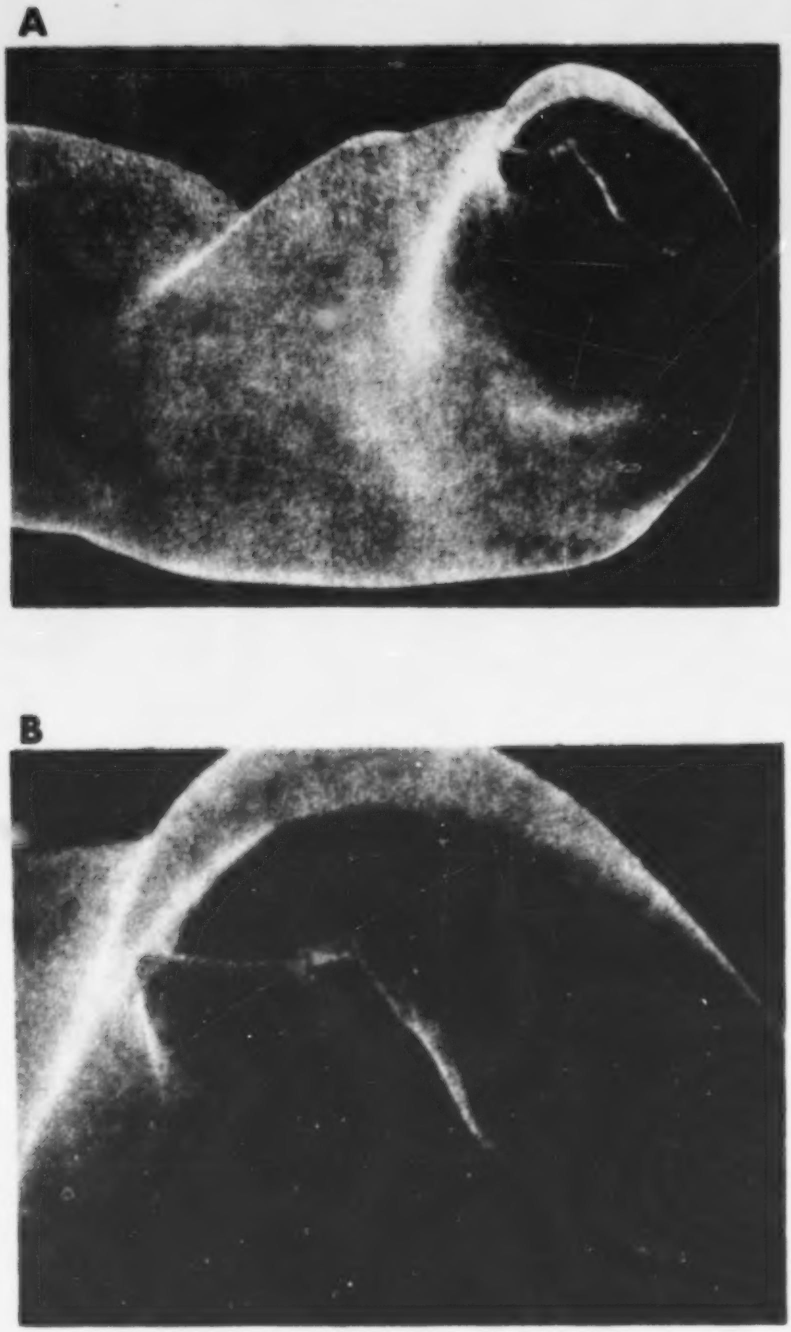


FIGURE 38 - COLD FRACTURE FOUND IN A SEVERLY NOTCHED SEGMENT OF FILAMENT. (A) = 4000X. (B) = 12000X

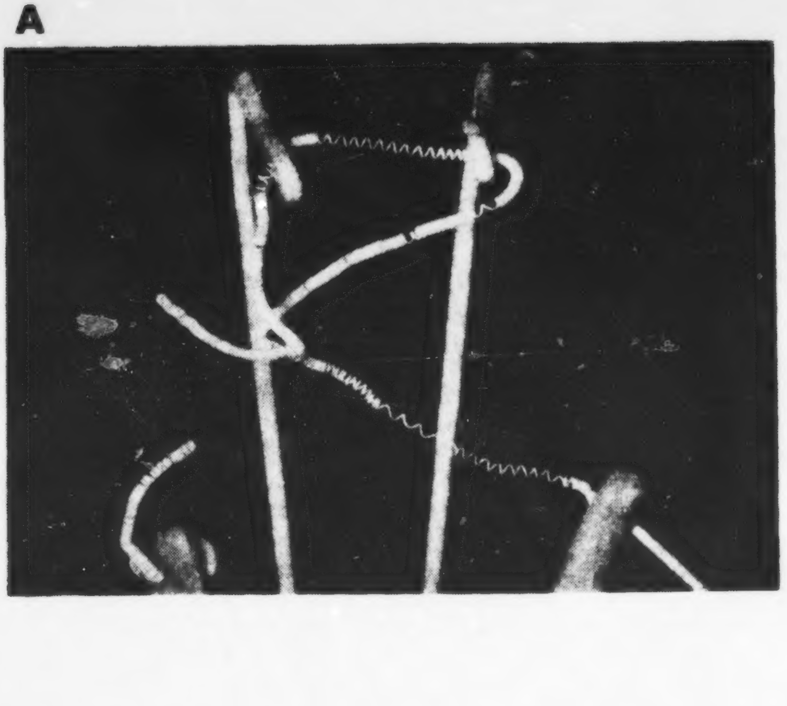


FIGURE 39 - BULB AGED 210 HOURS SUBJECTED TO 1672 G'S (OVER 1.4 MSEC; TEST 1) IN WHICH THE FILAMENT HAS CROSSED TOGETHER AND SHORTED OUT (A). FRACTURE AREA OF THE SAME BULB (B).

8.3 When filament coils touch together, the resultant electrical circuit represented by the filament is much shorter and hence has less resistance. Since the voltage supplied to the bulb is a constant 28 volts d.c., according to Ohms Law, (V = IR) if R (resistance) decreases and V (voltage) remains constant, then I (current) must increase. The increased current flowing through the short circuit will cause the filament to fail at a weak spot, not necessarily coincident with the contact point. Examination of a typical fracture area (see Figure 39b) revealed that the filament thinned and rounded itself off consistent with a high temperature induced failure. Also evident was the widening or bulging of the filament near the final fracture. This 'aneurism' type of effect was found to be characteristic of a filament fracturing due to excessive current (or voltage), and will be discussed under the section titled 'burn-outs'. In Figure 40a, another hot-fractured filament (aged 210 hours) is shown; however, in this example, the impact was in excess of 4000 gs and the time duration was short enough (0.18 msec) that resonance of the support posts occurred. The filament had 'snaked' so severely that filament contact occurred in several locations. (Note the random uncoiling and snaking of the filament which is characteristic of a hot filament at impact). Examination of the fracture surface (Figure 40b) revealed a similar rounding or smoothing out of the tip of the fracture and an aneurism effect near the final fracture. An interesting finding was that in all the areas where hot filament contact occurred, no evidence of melting was found. This was surprising as it was expected that in general when coils touch together, some type of welding should occur due to high contact resistance. Tests also revealed that in many cases welding or melting was not always evident during hot impacts, even at the fracture location. In these cases, fractures occurred without short circuit of the filament, and melting would not be expected as the temperatures would be kept below the melting point. The lack of molten tungsten is not sufficient evidence to conclude that a bulb was cold at impact. Welding or local melting, however, can occur when a hot filament is subjected to impact. The filament can sometimes slip along a grain boundary but not completely sever; or even break loose only to reweld somewhere else. Figures 41 and 42 show a hot filament (aged 48 hours) that

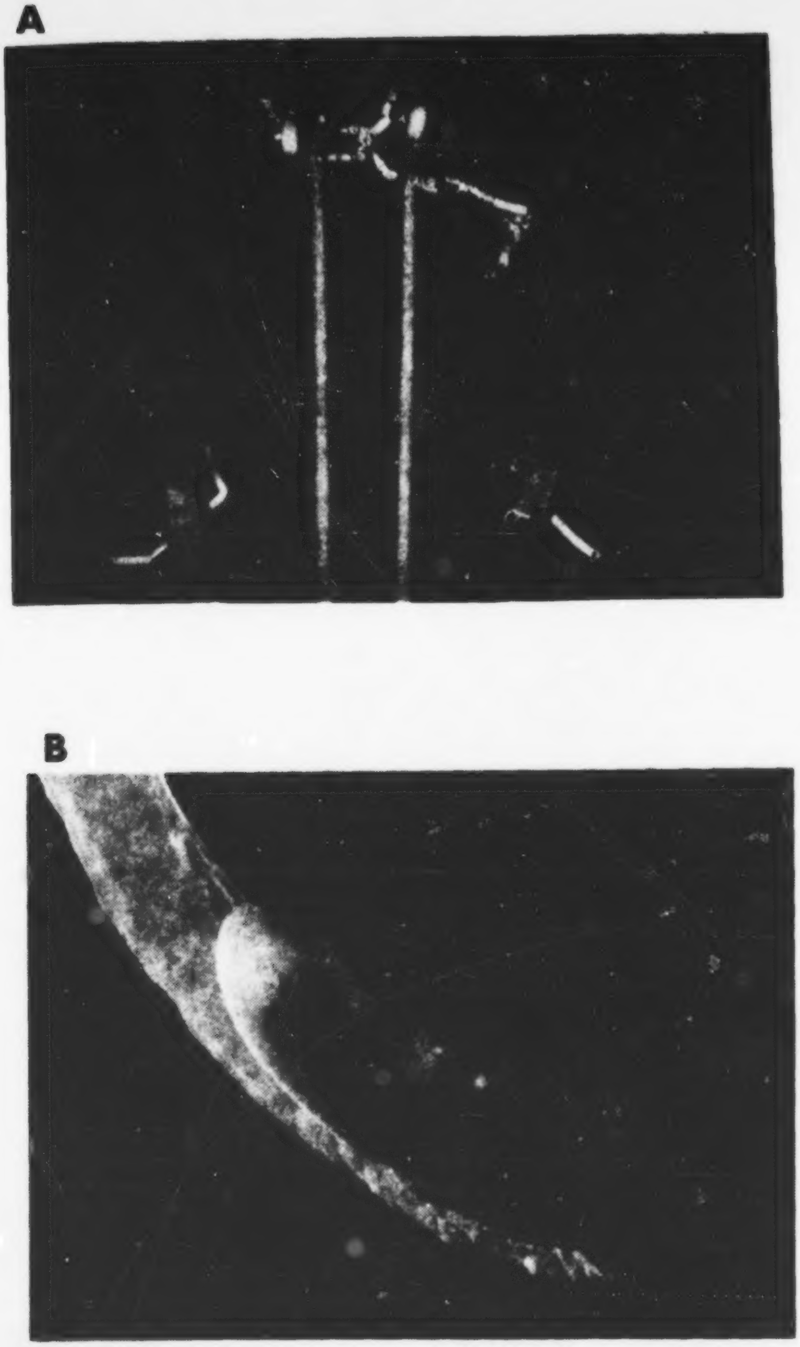


FIGURE 40 - BULB AGED 210 HOURS SUBJECTED TO IMPACT IN EXCESS OF 4000 G'S (OVER 0.18 MSEC) (A) = 20X. FRACTURE SURFACE DETAILS SHOWS ROUNDED FILAMENT TIP AND 'ANEURISM' EFFECT. (B) = 2000X

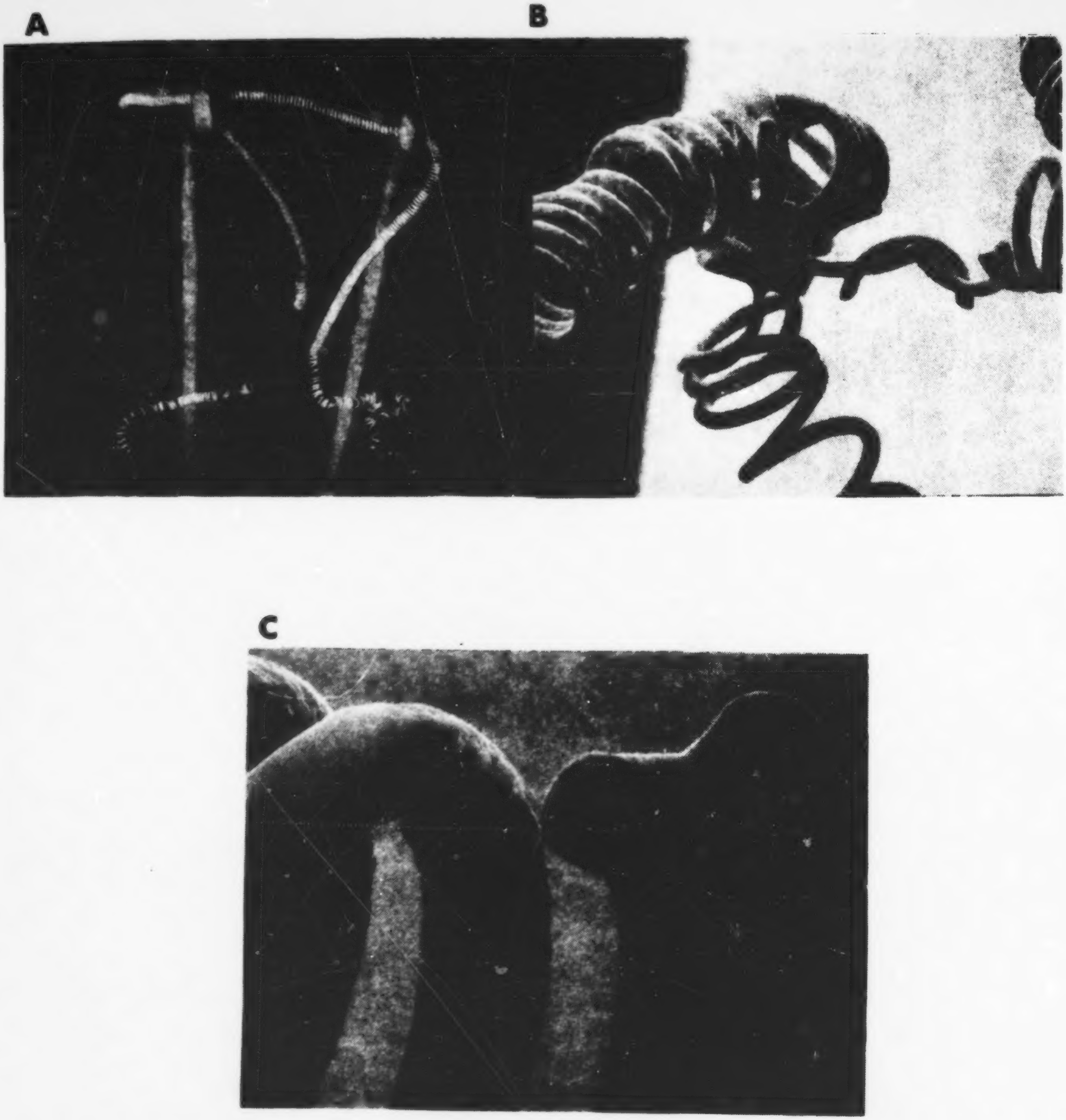


FIGURE 41 - HOT FILAMENT (AGED 48 HOURS) SUBJECTED TO 1529 G'S - OVER 1.7 MSEC (A) = 20X. NOTICE SLIPPAGE THAT HAS OCCURRED ACROSS GRAIN BOUNDARIES AND LOCAL REWELDING. (B) = 300X. (C) = 2000X

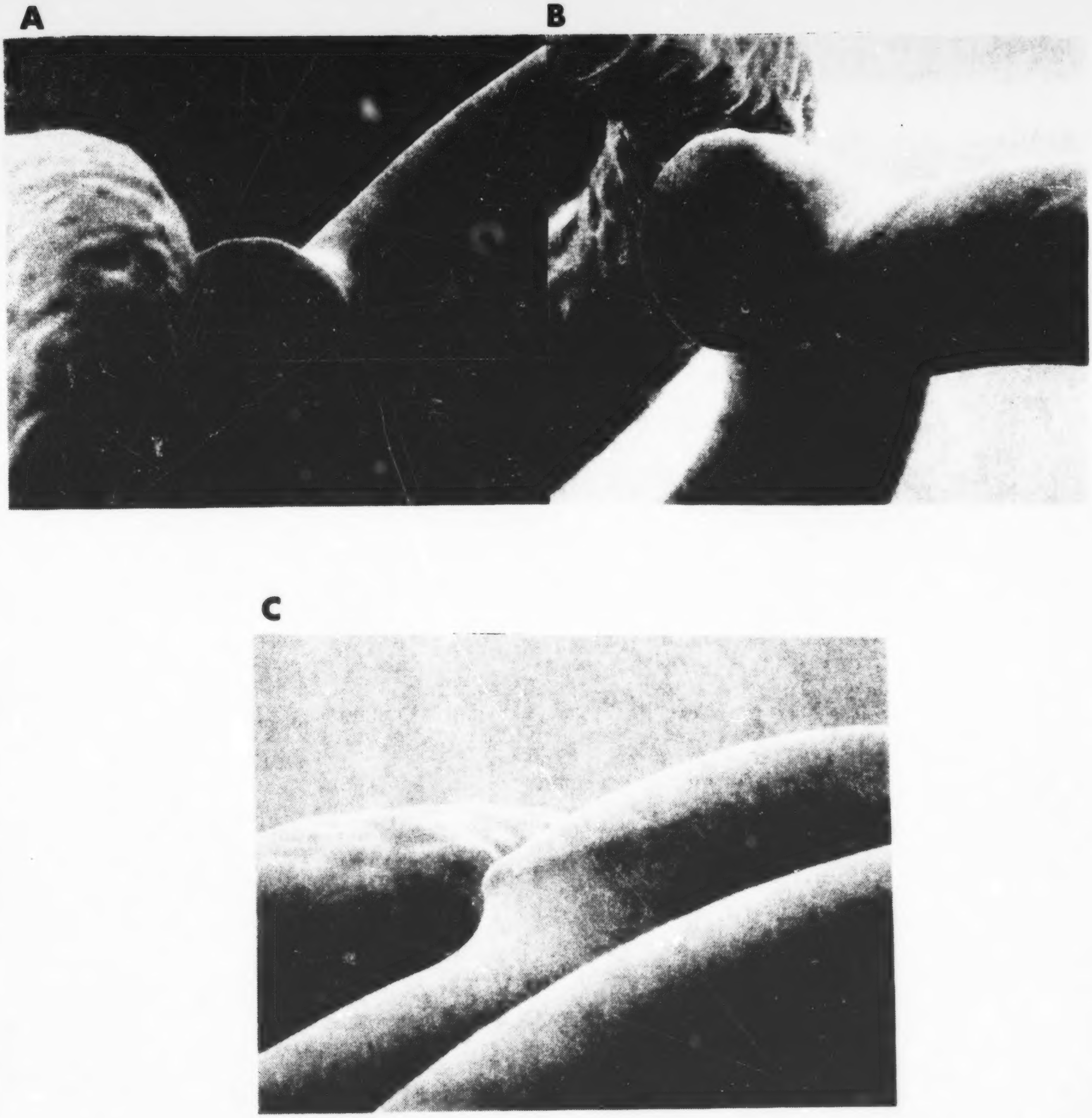


FIGURE 42 - EXAMPLES OF FILAMENT REWELDING (A & B = 3000X) AND GRAIN BOUNDARY ACTION THAT OCCURRED DURING HOT IMPACT (SAME BULB AS FIGURE 41). C = 3500X

was subjected to 1530 g over 1.7 msec in which hot grain boundary slippage has occurred and small segments of coil have completely separated and rewelded.

8.4 Other types of fracture surfaces found in hot impacted bulbs are shown in Figure 43. These fractures can be characterized by their lack of sharp edges. Rounded or smooth fracture edges appear to be a general characteristic of hot filament fractures. When analysing a light bulb, the presence of a cold fracture does not necessarily mean that the bulb was cold at impact, whereas the presence of melting is good indication of a hot filament at the time of failure. This may sound obvious, but consider the case when a fracture occurs while a filament is incandescent. Once the bulb is open circuited due to initial fracture, current no longer flows and any subsequent breaks will begin to appear cold. Also, in cases of local melting, the molten surface may break off either during the latter part of the impact pulse or possibly due to large thermal gradients created by the molten surface, leaving behind no trace of local melting.

8.5 The terms 'ductile' and 'brittle' fracture cannot readily be applied to light bulb analysis. Materials have traditionally been classified as ductile and brittle via the relatively slow tensile test. For example, if the material elongated more than 10%, it was considered ductile and fractured in traditional 'cup-cone' style. By comparison, less than 10% elongation was considered brittle and was generally associated with a granular type of fracture. A fracture from a filament subjected to impact (one in which shorting does not occur) is far from being 'slow'. The high rate of fracture gives rise to a 'brittle' fracture appearance as a result of the material's strain rate sensitivity. For example, pulling a piece of "Silly Putty" apart slowly, results in a long-necked, dutile fracture. Pulling the same putty apart at a high rate of speed produces a brittle fracture. The 'slow' type of fracture does not occur during impacts or crashes. Even though the tungsten may be operating above its brittle-ductile transition temperature, fractures due to impact will typically reflect characteristics of traditional 'brittle' fracture.

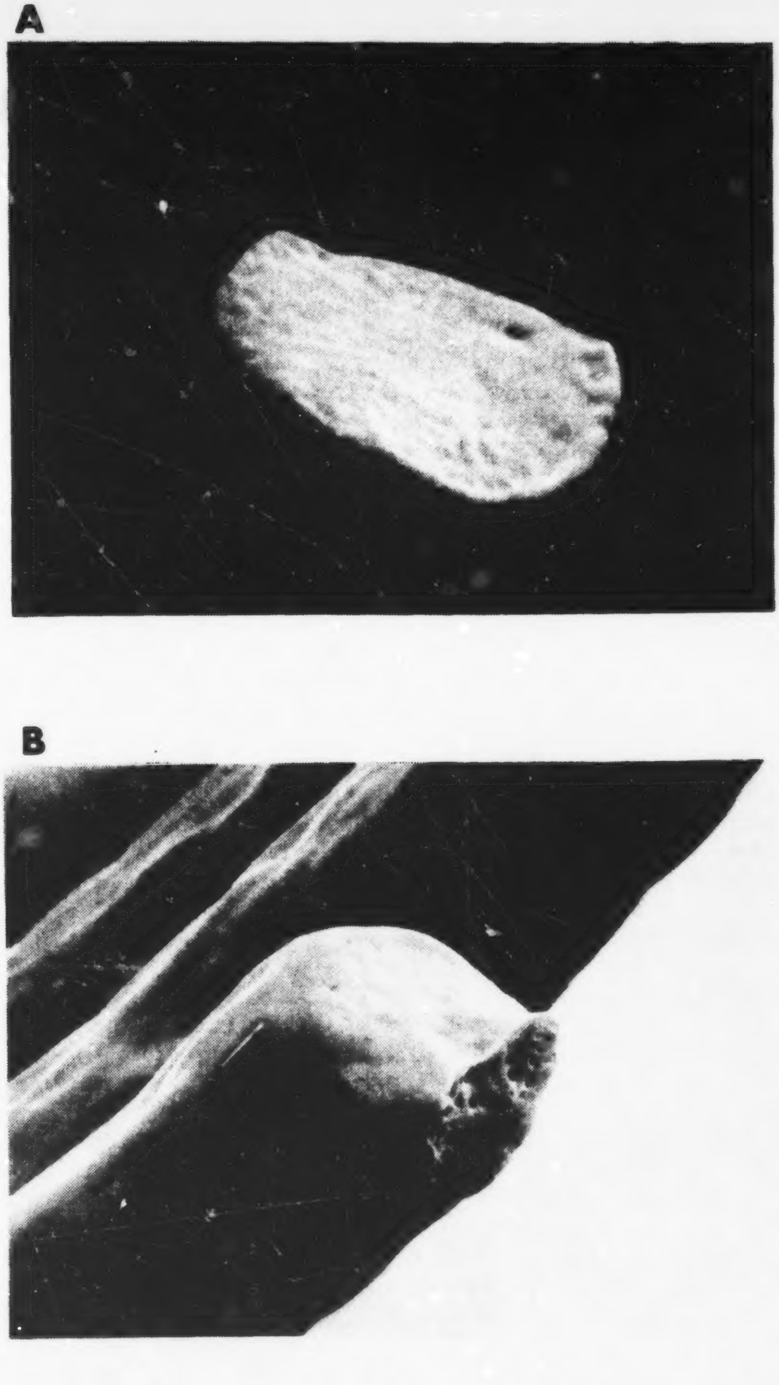


FIGURE 43 - EXAMPLES OF FRACTURE THAT HAVE OCCURRED DURING 'HOT' IMPACT. NOTICE THE ROUNDED FRACTURE EDGES.

9.0 BURN-OUTS

9.1 It is important to distinguish between an impact induced hot failure, a burn-out failure due to old age, and a burn-out failure due to overvoltage. First of all, impact-induced hot failure due to short circuiting will yield fracture characteristics similar to burn-out failures due to overvoltage, but will also exhibit severe deformation consistent with high impact. Burn-out failures due to overvoltage do not generally exhibit filament deformation. Second, a relatively new filament will obviously not have burned out due to old age. Figure 44 shows some filaments that have burned out due to old age. Notice the severity of the notching and the molten shapes that occur at the final fracture areas where extreme local heating occurred. High-speed film was taken of type 327 bulbs being subjected to an excessive voltage. If sufficient voltage is experienced, the filament burns out at one or both contact posts in an explosive manner (see Figure 46a). Furthermore, the two burn-outs at each contact post do not necessarily occur simultaneously, but can occur a few milliseconds apart. This non-simultanous fracture phenomena may be due to the behaviour of the coiled filament's inductive reaction to a sudden voltage change, which, by virtue of its geometry, is capable of storing energy in magnetic fields created by the current flowing within the coils. The stored energy is released as a result of the circuit being broken. These tests were done with alternating current, because direct current power sources available were not of sufficient magnitude; however this inductive phenomena would likely occur with d.c. voltage as well. Examination of the filament segment that remained attached to the contact post revealed quasi-spherical circular globules of molten tungsten (Figures 46b and 46c). Burn-outs due to overvoltage also exhibit molten surfaces and a widening of the filament similar to the impact-induced hot fractures previously described (Figure 46d). High voltage burn-outs should be considered in analysing light bulbs because of the possibility of aircraft systems shorting prior to impact. Analysis of high voltage burn-outs proved useful in the investigation of the Ocean Ranger Marine Disaster in which the control panel was determined to have shorted out (Detailed Ocean Ranger Light Bulb Analysis can be found in Appendix "B")

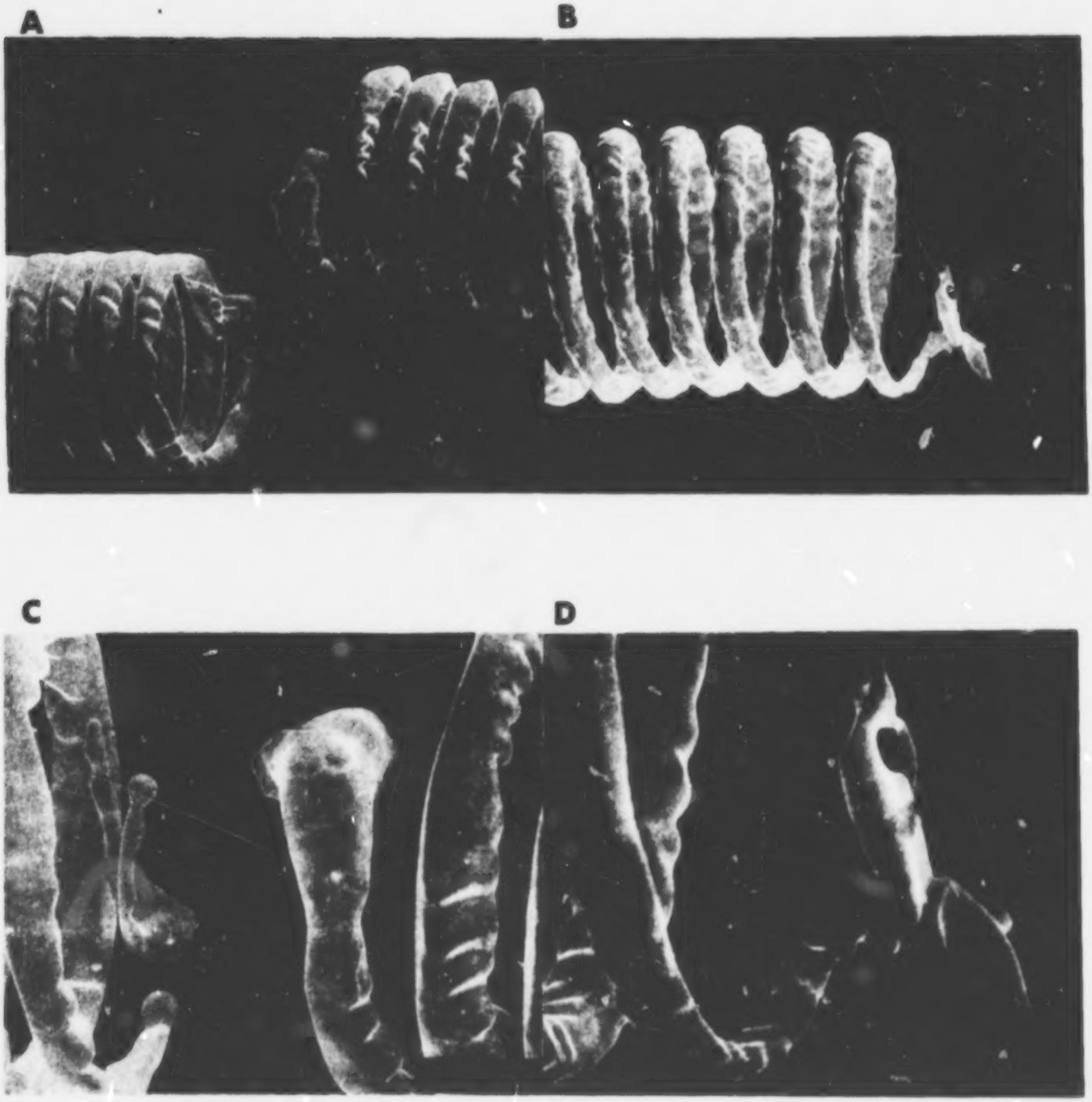


FIGURE 44 - EXAMPLES OF BURN-OUT DUE TO OLD AGE. THE FILAMENT HAS NOTCHED TO THE EXTREME SUCH THAT IT HAS BURNED OUT IN NORMAL OPERATION.

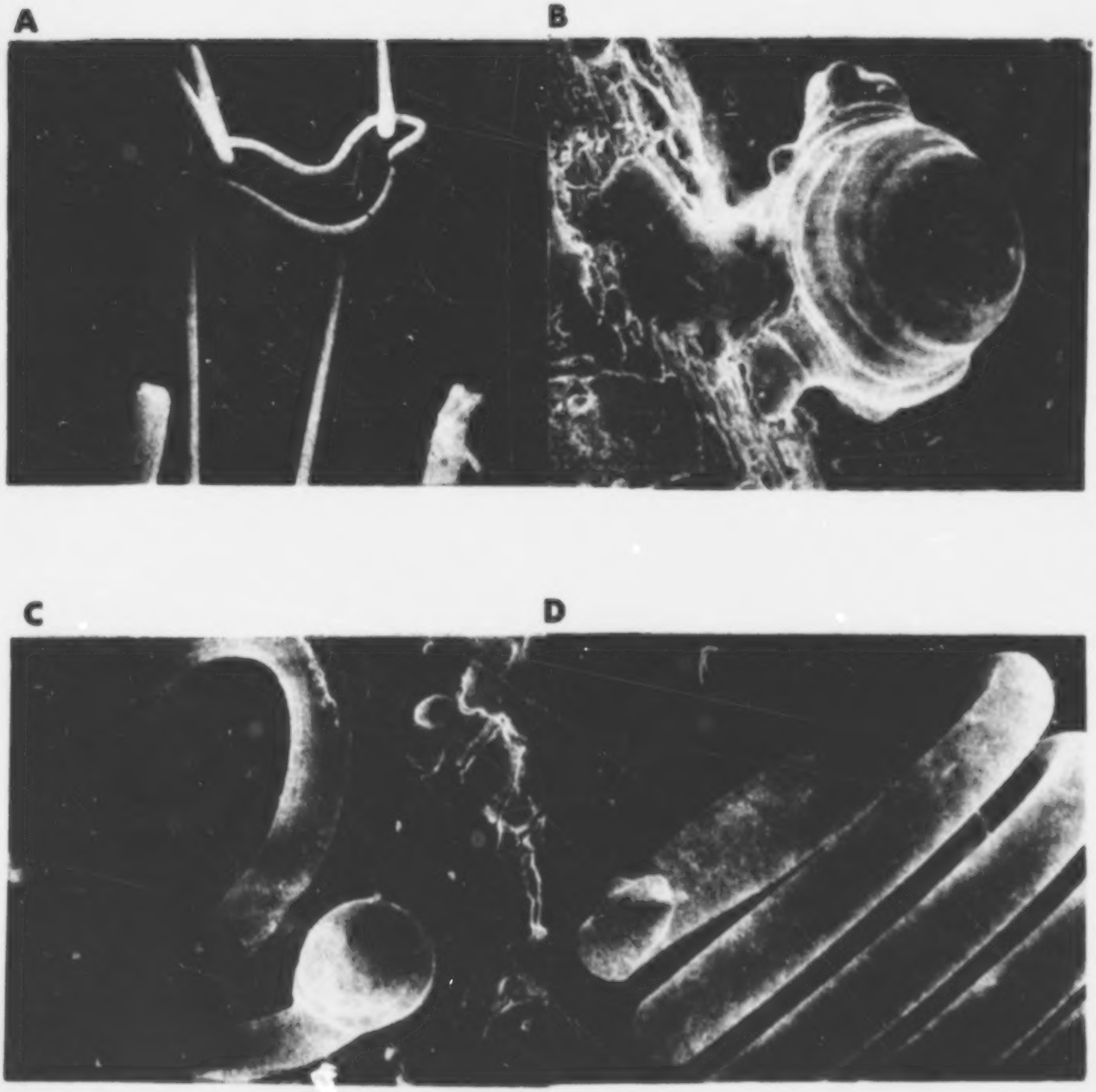


FIGURE 45 - LIGHT BULB SUBJECTED TO EXCESS VOLTAGE. FAILURE TYPICALLY OCCURS AT BOTH CONTACT POSTS LEAVING GLOBULES OF MOLTEN TUNGSTEN AT THE CONTACT POSTS.

10.0 INCANDESCENCE-TIME TESTS

10.1 Quite often in aircraft accident investigation, the question arises as to the time required for a light bulb to reach incandescence following application of electrical power. Scenarios have been suggested in which a light bulb that is initially off can become incandescent during the crash impact sequence, and then exhibit hot characteristics to indicate that it was on prior to impact, when in fact, it was not. If the time required for the light bulb to fully illuminate is greater than the time required for the major part of the impact sequence, then the above scenario is not possible. To answer this question, a computer controlled test was devised, utilizing a high-speed camera and an oscilloscope. The high-speed camera was focused on an unlit GE-327 bulb. An auxilliary lens was attached to the back of the camera, focused on the oscilloscope CRT. The oscilloscope display was bright enough to penetrate through the back of the film and provide a visible trace. The high-speed camera was then remote controlled through the computer relay actuator. As well, the relay actuator controlled the voltage to the bulb which was monitored by the oscilloscope. Solid state switching was utilized to eliminate relay bounce. A short computer program was used to start the high-speed camera; then, after a programmed delay (film start-up time), voltage was applied to the bulb and again after a programmed illumination time, was removed. By counting the number of frames on the high speed film from the oscilloscope trigger to maximum incandescence, a good approximation of the illumination time was made. Conversely, the time to cool was taken as the time required before the filament did not radiate sufficient energy to illuminate the film. For the GE-327 bulb, illumination time was found to be about 48 msec and the time to cool was about 50 msec. Illumination tests were also carried out on GE-313 bulbs, and the times required for illumination and cool down were about 48 and 98 msec respectively. When an aircraft impacts the ground at relatively high speed and steep angles, the impact sequence is relatively short and the possibility of a false light bulb indication diminishes. If, however, an aircraft initially strikes a tree and some part of the aircraft becomes damaged, caution and warning lights could be triggered. The aircraft could subsequently contact the ground with impact forces severe enough to cause damage to these light bulbs, which could mislead investigators as to the pre-crash status of the aircraft.

11.0 SOME POINTS ON 'G' LEVELS

11.1 Basic kinematics states that if an aircraft is travelling at a certain speed before impact with the ground and stops in a certain distance, a 'g' level or deceleration level can be calculated. The velocity of the aircraft just prior to impact determines its kinetic energy at the moment of impact. This kinetic energy defines the maximum energy that can be dissipated in the crash. However, the 'g' level is not necessarily proportional to the velocity of an aircraft prior to impact. If a penny is dropped from a height of 1 metre onto a steel floor, it can experience several thousand g (but of extremely short duration). The same penny dropped from the same height onto a pillow, while attaining the same final velocity prior to impact, may only experience a few g (of long duration). The g level calculated in aircraft crashes using general kinematics principles gives the investigator a general feel for the overall g level of the accident. However, it is important to realize that individual parts of an aircraft, instrument panels for example, can and will experience far different g levels than those calculated by the general kinematics equations, as the complex structure of the aircraft crushes under impact. An accelerometer mounted in the nose of an aircraft may see spikes of several tens of thousands of g while one in the tail experiences g levels orders of magnitudes smaller. Kinematic analysis of the accident yields the average g level of the centre of mass of the aircraft, a third, entirely different number. On occasion, the g level of the accident is calculated via kinematics, and then it is extrapolated to state that 'therefore every component on the aircraft saw a maximum g of such and such'. Such a statement would be incorrect. This study on light bulb analysis has demonstrated, for example, that a relatively new bulb must experience approximately 1000 g to exhibit observable damage. Ths does not mean the overall g level of the accident need be 1000 g (ie as calculated via kinematics), but only, that the bulb, at some point in the crash, saw 1000 g for sufficient duration to cause damage. Finally, stating a g level without a time duration attached to it is misleading.

12.0 ACTUAL CRASH ANALYSES

12.1 Throughout this study, analyses of light bulbs from real aircraft accidents were performed, A few representative project reports have been included in Appendix "C". Actual crash analyses revealed the need for study of filament behaviour under high g level impacts and the need to study the differences between bulb types and manufacturers. Energy dispersive X-ray analysis (Figure 46) of General Electric, Chicago Miniature, and Stanley bulbs revealed that they were all composed of 99.98% tungsten. Differences in filament behaviour from manufacturer to manufacturer is likely due to differences in microstructure and recrystallization temperature, possibly resulting from doping techniques and manufacturing processes.

12.2 During analyses of light bulbs from actual aircraft accidents, it was found that a hot filament could come in contact with the glass envelope. The hot filament or filament fragment could then fuse or melt into the glass envelope. This type of damage was not obtained during the laboratory impacts, likely as a result of insufficient impact forces. ASE report LP 342/84 of Appendix "C" contains some examples of bulbs that contain segments of filament melted into the glass envelope.

12.3 If a light bulb's glass envelope were to break during impact, while the filament was incandescent, the filament would oxidize instantly when the vacuum was broken. ASE report LP 384/84 contains an example of a rotating beacon filament in which the glass envelope was broken during impact. Energy dispersive X-ray analysis revealed that an oxide layer had formed around the filament, indicating that it must have been incandescent at impact. Small pieces of glass may also contact the hot filament when the envelope is broken, in which case the glass will typically adhere to the filament (refer to LP 384/84). This type of evidence must be analysed carefully, since glass fragments can also adhere to a cold filament because of electrostatic attraction forces. Thus, when removing the glass envelope from a bulb for SEM Analysis, the microscopic fragments which may adhere to the cold filament should not be confused with a fragment that has melted onto a hot filament.

TRACOR-NORTHERN SPECTRAL PLOT

1ST HALF: IP 55/84 FILAMENT MATERIAL G.E. BULB LT= 200 SECS 0.020 KE

V

COUNTS F.S.= 8192

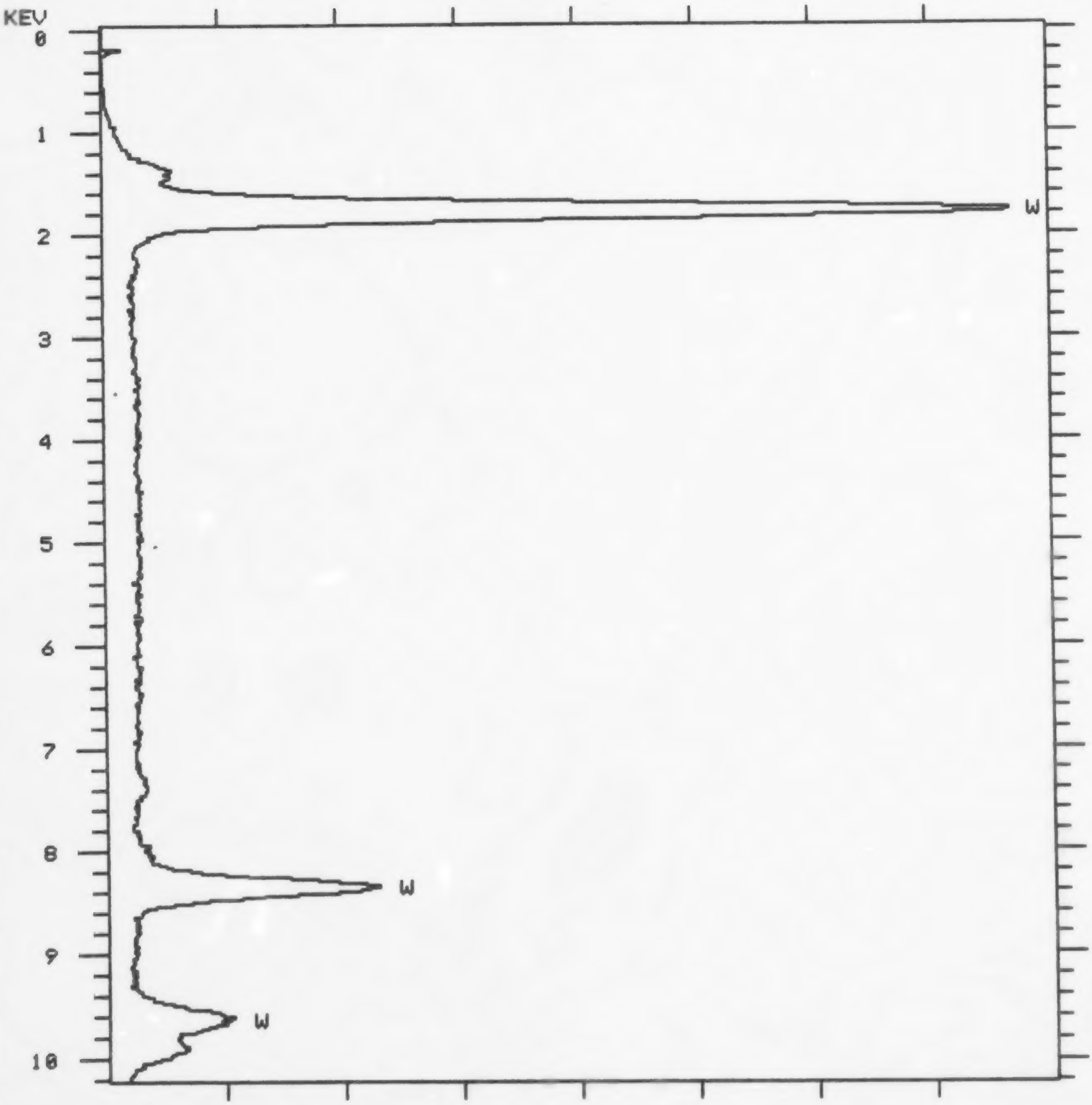


FIGURE 46 A) Energy Dispersive X-ray analysis of General Electric bulb.

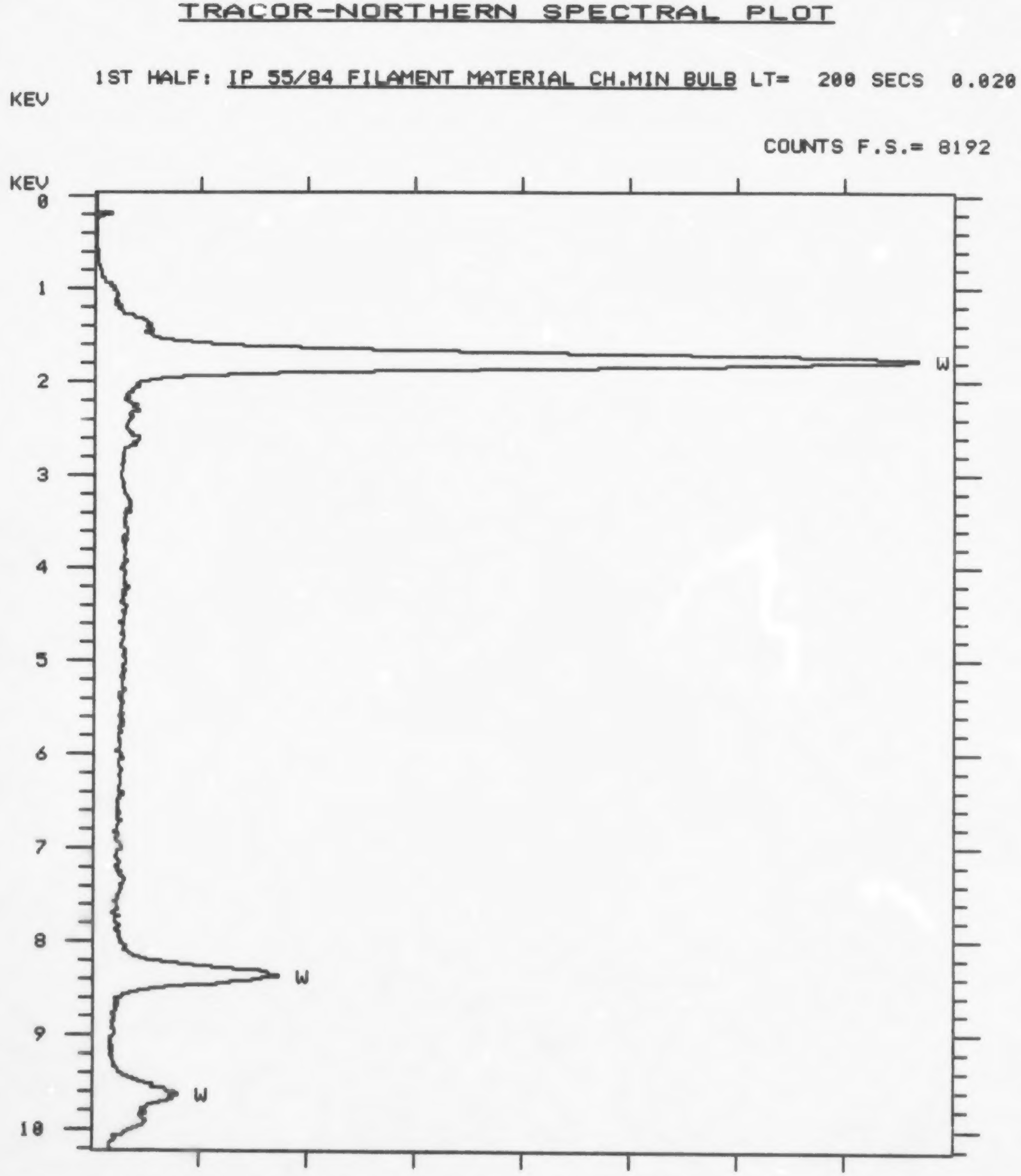


FIGURE 46 B) Energy Dispersive X-ray analysis of Chicago Miniature bulb.

TN FLEXTRAN [11-E]

SDMP0-2A/80 SPEC.PLT

TRACOR-NORTHERN SPECTRAL PLOT

1ST HALF: IP 55/84 FILAMENT MATERIAL STANLEY BULB LT= 200 SEC
S 0.020 KEV

COUNTS F.S.= 8192

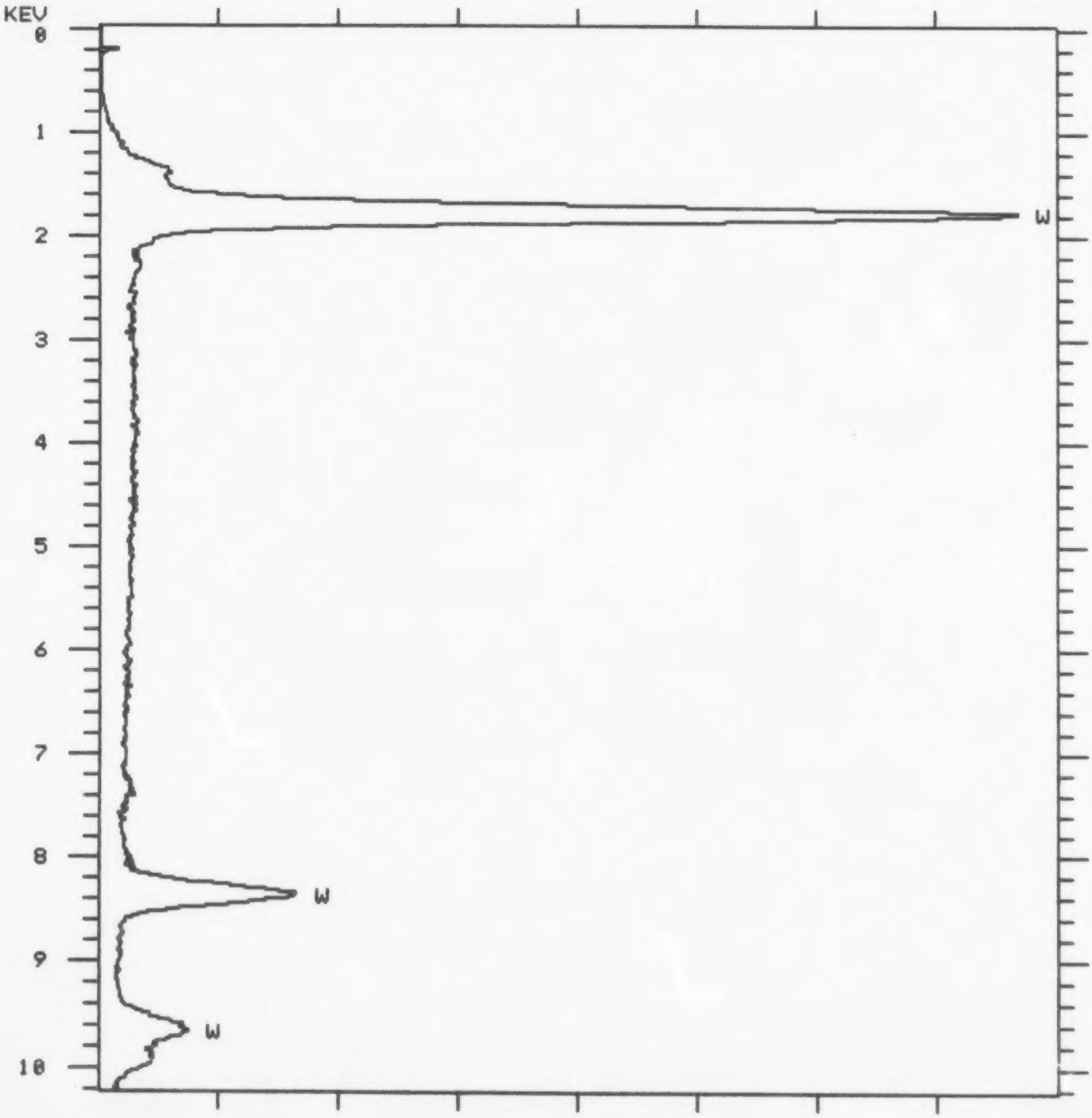
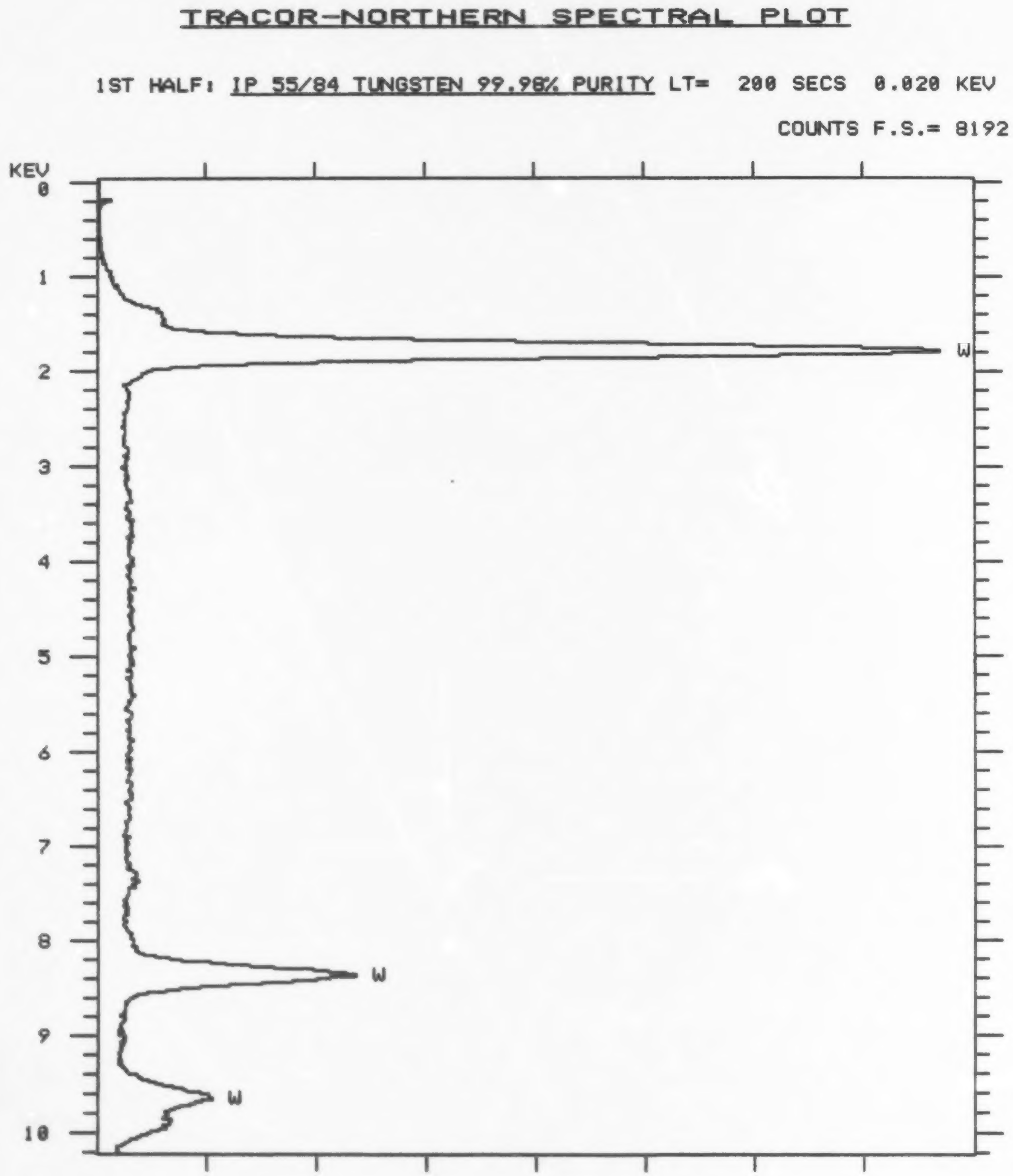


FIGURE 46 C) Energy Dispersive X-ray analysis of Stanley bulb.



TRACOR-NORTHERN SPECTRAL PLOT

1ST HALF: IP 55/84 TUNGSTEN 99.98% PURITY LT= 200 SECS 0.020 KEV

COUNTS F.S.= 8192

FIGURE 46 D) Energy Dispersive X-ray analysis of Tungsten.

13.0 SUMMARY OF FINDINGS

13.1 The types of damage which convey useful information relating to the state of light bulbs at impact are:

1) general deformation of the filament;
2) local deformation (stretching and uncoiling of the filament);
3) fracture of the filament;
4) filament/glass fusion;
5) burnout;
6) oxidation (due to glass envelope breaking or developing a leak).

13.2 The two most significant factors which affect filament damage are d.c. notching and impact severity. Impact components of short enough duration cause resonance of the bulbs' support posts, and thus a higher than normal response and greater filament damage.

13.3 Of the two aging mechanisms, (d.c. notching and evaporation) d.c. notching was found to be by far the predominant life influencing factor. Filament age, as reflected by the severity of d.c. notching, reduces the strength of a filament in both a hot and cold state.

13.4 New filaments when cold can withstand higher g levels than when hot, as hot filaments begin to show deformation at approximately 1500 g (over 1.5 msec.). As the filament ages, it becomes increasingly fragile until eventually even normal handling can fracture an extensively aged cold filament.

13.5 New GE-327 bulbs when hot showed no signs of local deformation even to 3000 g (1.0 msec.). As the bulbs were aged, local deformation became increasingly evident in all hot impact tests. Fracture eventually occurred at impact in many cases due to filament contact with itself and shorting occurring.

13.6 When tested cold, GE-327 bulbs, of any age showed no significant signs of general or local deformation throughout the non-resonant impact test range until filament fracture. In the high g level resonance range, local deformation was evident in relatively new bulbs, but was confined to small areas. Aged bulbs, when tested cold, typically fractured before deformation could occur. Cold local deformation typically occurs because the filament is whipped by the support posts; hence it is not expected to be found in any bulbs which are configured with unsupported filaments (except coiled coil type bulbs in which the primary coil can stretch cold).

13.7 Filaments do not age uniformly along their length due to the temperature gradients resulting from the heat sink effects of the support posts and contact posts. This results in a non-uniform microstructure, and hence non-uniform filament behaviour at impact and non-uniform fracture characteristics.

13.8 When analysing light bulbs, it is essential to examine as large a group of bulbs as possible which are known to have been subjected to essentially the same impact forces. If, for example, a bulb is discovered exhibiting severe filament deformation characteristic of a hot filament, other bulbs of similar age exhibiting no deformation become evidence of an "off" status.

13.9 To avoid misleading representations of the aircraft pre-impact status, it is necessary to estimate the time of the accident impact sequence. Traditional methods of stopping distance and speed and attitude prior to impact can provide a reasonable time estimate which can then be compared to the illumination and/or decay times of lights previously stated. The times stated comprise only the illumination time and therefore do not take into account the triggering sensor mechanism and linkage delays, etc. The illumination time is the absolute minimum time that a system could possibly activate a light, but the overall total system reaction time should be considered, and may be considerably longer.

14.0 RECOMMENDATIONS

14.1 Additional study should be carried out to explore more fully various types of light bulbs from different manufacturers. Specifically, bulbs that do not contain support posts should be studied as well as bulbs which contain coiled coils (double helix) as the dynamics at impact will be will be quite different. These non support post types of bulbs are increasingly being utilized in aircraft applications because of their small size.

14.2 Future work should include testing of light bulbs in the higher impact ranges, including short duration pulses that cause resonance.

14.3 Damage boundary curves should be generated for various types of bulbs and age groups.

14.4 Further tests should be carried out with power being interrupted during the impact sequence to more fully explore the effects of current disruption as a result of impact.

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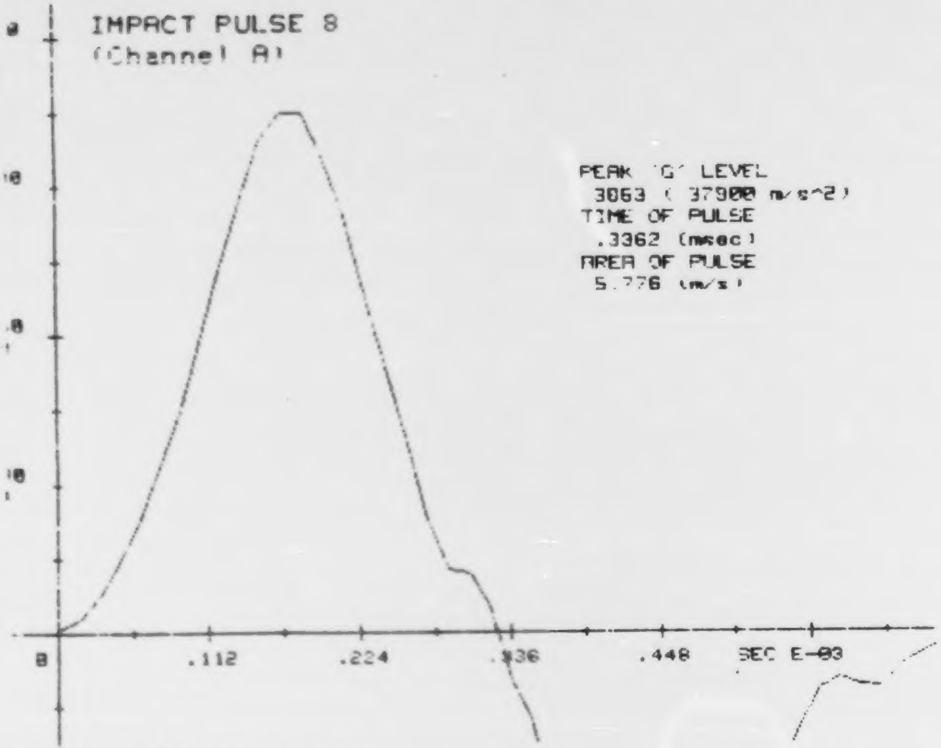
APPENDIX "A"

IMPACT TEST DOCUMENTATION

Note: PULSE "A" MEASURES TABLE
PULSE "B" MEASURES FIXTURE

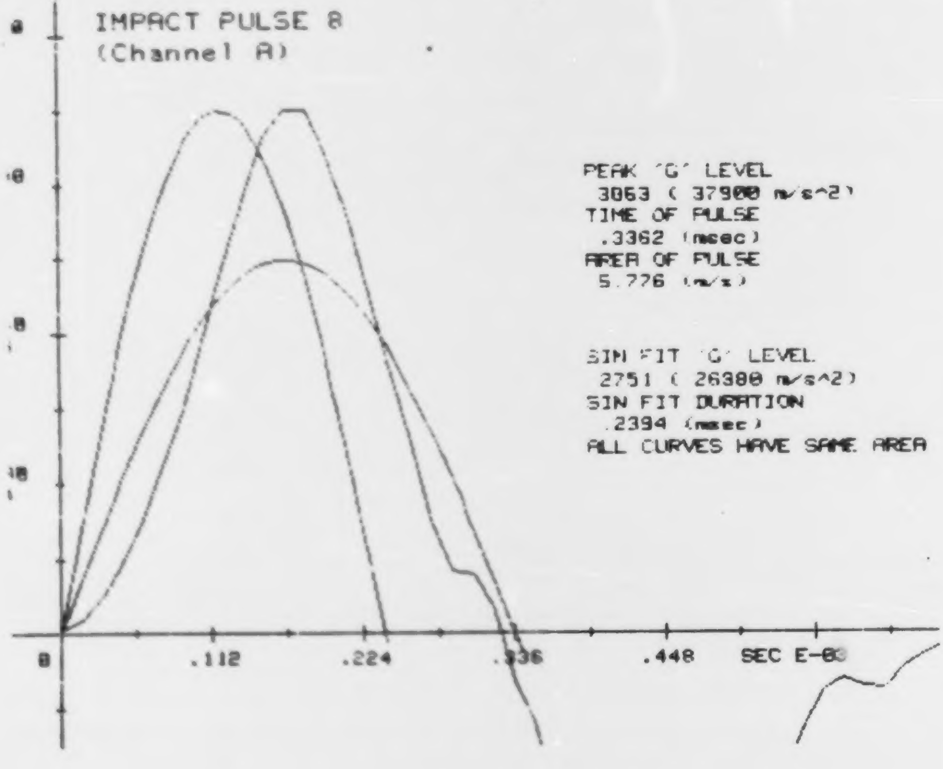
A-2

```
          TEST DATE           JULY 20 1984
          TEST NUMBER         8
---------------------------------------------------------------

BULB TYPE ( 1 -BULBS)                          GE-327
BULB #1 AGE (Hours)                             0
BULB #2 AGE (Hours)                             0
BULB #3 AGE (Hours)                             0
BULB #4 AGE (Hours)                             0
IMPACT MEDIUM                                  HAMMER
TEST VOLTAGE                                   28
NUMBER OF SHOCK CORDS                           0
ACCELEROMETER (Channel A)                       827083
ACCELEROMETER (Channel B)                       827086
GAINS                                           1          1
CHANNEL A ONLY IN CENTER OF RESONANT FIXTURE




RESISTANCE...
           BEFORE       AFTER        DELTA
---------------------------------------------------

BULB 1       0            0            0
BULB 2       0            0            0
BULB 3       0            0            0
BULB 4       0            0            0




            DAMAGE REPORT --> TEST 8
NUMBER  DAMAGE       (Peak G-  3863.4  )
--------------------------------------------------------------------

BULB 1   Gen. stretch Loc. stretch
BULB 2
BULB 3
BULB 4

COMMENTS...
BULB 1   HIGH SPEED FILM TAKEN - SEVERE STRETCH AND SNAKING
BULB 2
BULB 3
BULB 4
```



IMPACT PULSE 8
(Channel A)

PEAK 'G' LEVEL
3063 (37900 m/s^2)
TIME OF PULSE
.3362 (msec)
AREA OF PULSE
5.776 (m/s)

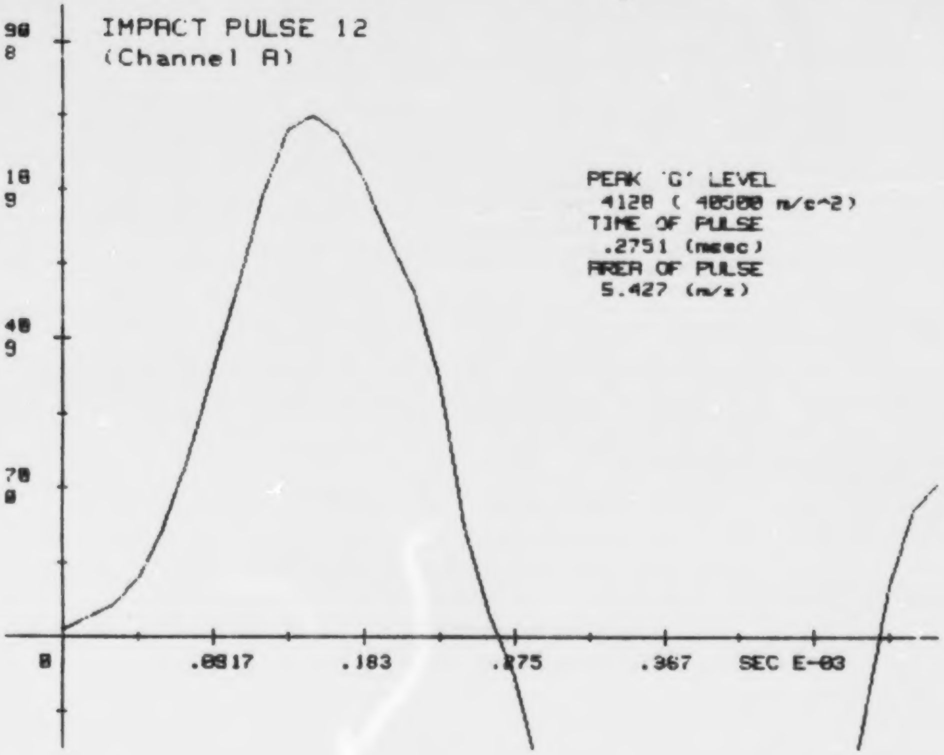


IMPACT PULSE 8
(Channel A)

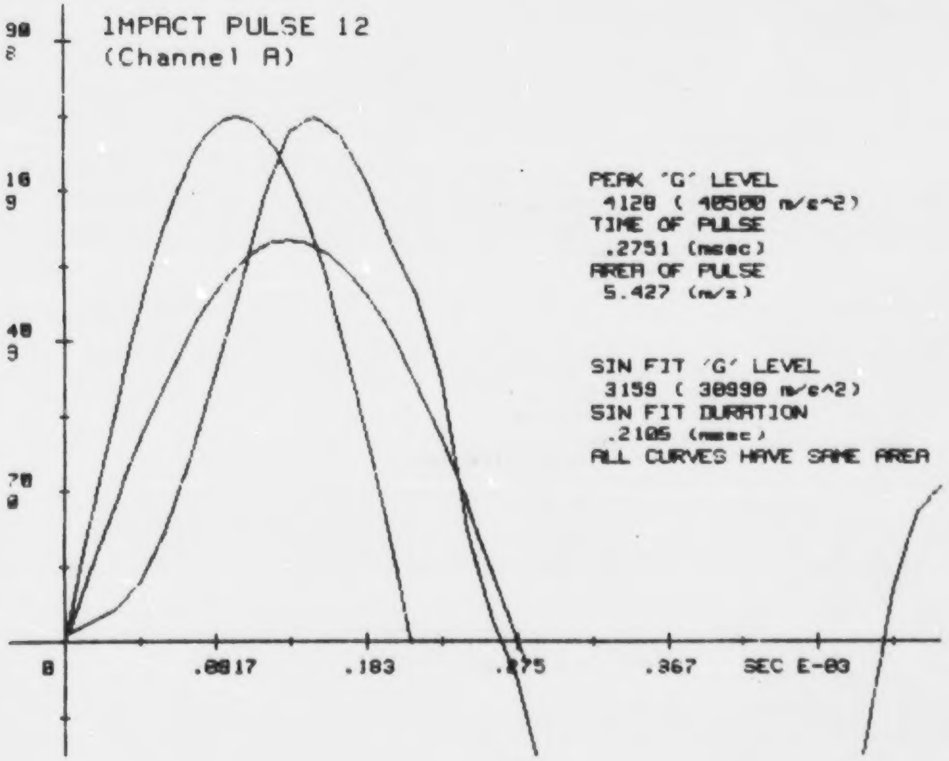
PEAK 'G' LEVEL
3063 (37900 m/s^2)
TIME OF PULSE
.3362 (msec)
AREA OF PULSE
5.776 (m/s)

SIN FIT 'G' LEVEL
2751 (26380 m/s^2)
SIN FIT DURATION
.2394 (msec)
ALL CURVES HAVE SAME AREA

```
          TEST DATE          JULY 20 1984
          TEST NUMBER        12
------------------------------------------------------------------

BULB TYPE ( 1 -BULBS)                    GE-327
BULB #1 AGE (Hours)                       0
BULB #2 AGE (Hours)                       0
BULB #3 AGE (Hours)                       0
BULB #4 AGE (Hours)                       0
IMPACT MEDIUM                            HAMMER
TEST VOLTAGE                             0
NUMBER OF SHOCK CORDS                     0
ACCELEROMETER (Channel A)                 827083
ACCELEROMETER (Channel B)                 827086
GAINS                                     1          1
FILMED @2000 F/S  SEM#261




RESISTANCE...
             BEFORE        AFTER         DELTA
-----------------------------------------------------

BULB 1         0             0             0
BULB 2         0             0             0
BULB 3         0             0             0
BULB 4         0             0             0




              DAMAGE REPORT --> TEST 12
NUMBER  DAMAGE       (Peak G-  4026.5  )
----------------------------------------------------------------------

BULB 1   Gen. stretch Loc. stretch
BULB 2
BULB 3
BULB 4

COMMENTS...
BULB 1   BEGINNINGS OF LOCAL STRETCH (COLD)  SEM #261
BULB 2
BULB 3
BULB 4
```

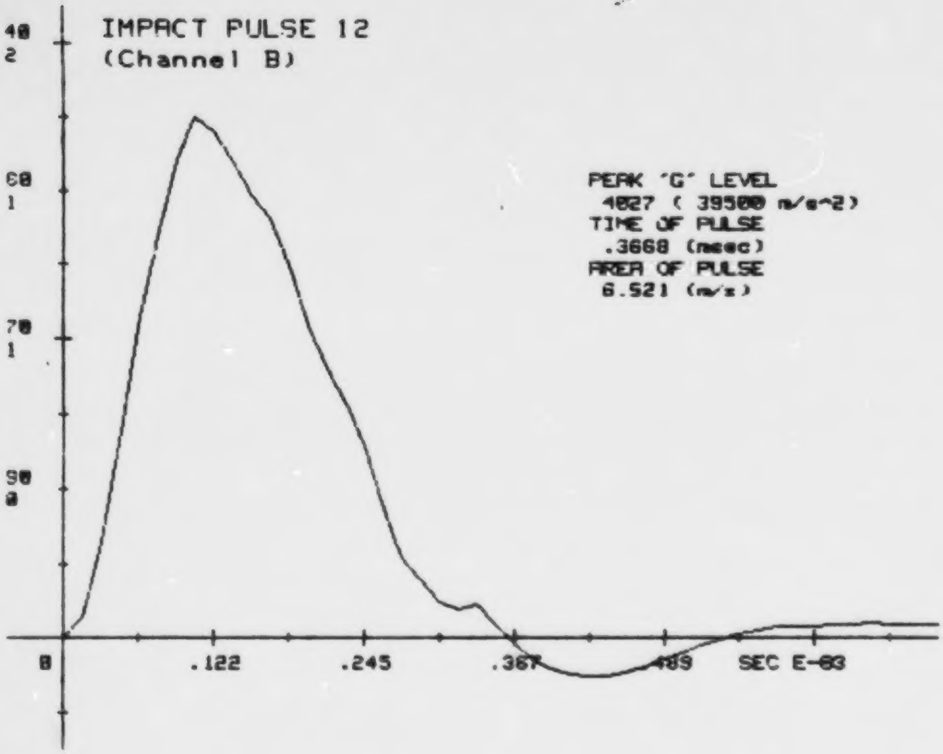


PEAK 'G' LEVEL
4128 (40500 m/s^2)
TIME OF PULSE
.2751 (msec)
AREA OF PULSE
5.427 (m/s)

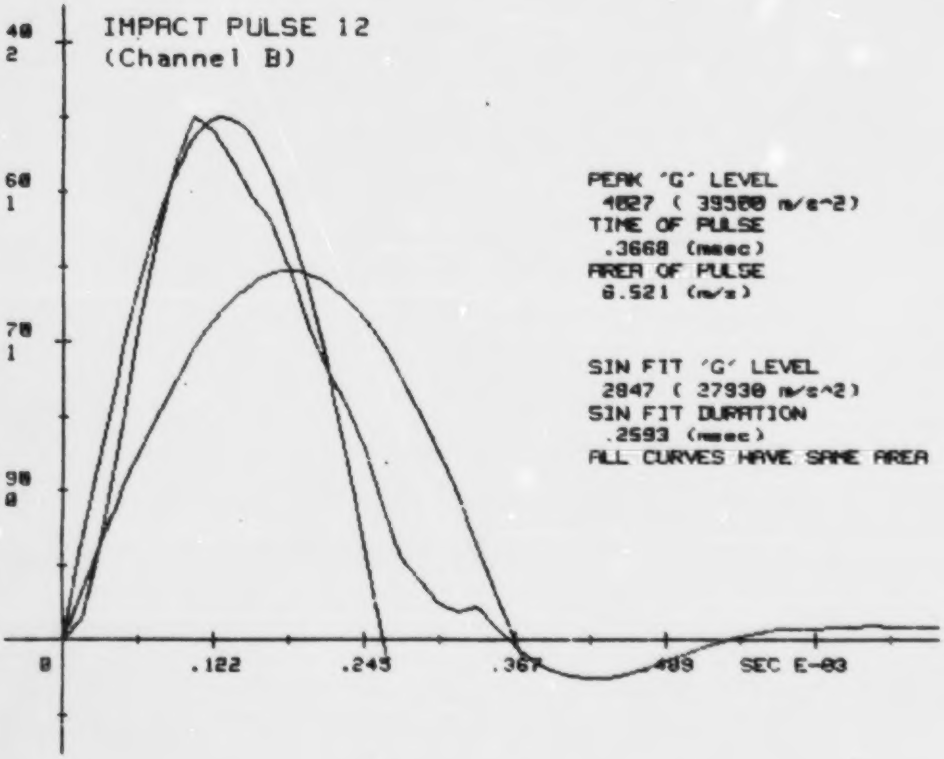


PEAK 'G' LEVEL
4128 (40500 m/s^2)
TIME OF PULSE
.2751 (msec)
AREA OF PULSE
5.427 (m/s)

SIN FIT 'G' LEVEL
3159 (30990 m/s^2)
SIN FIT DURATION
.2105 (msec)
ALL CURVES HAVE SAME AREA



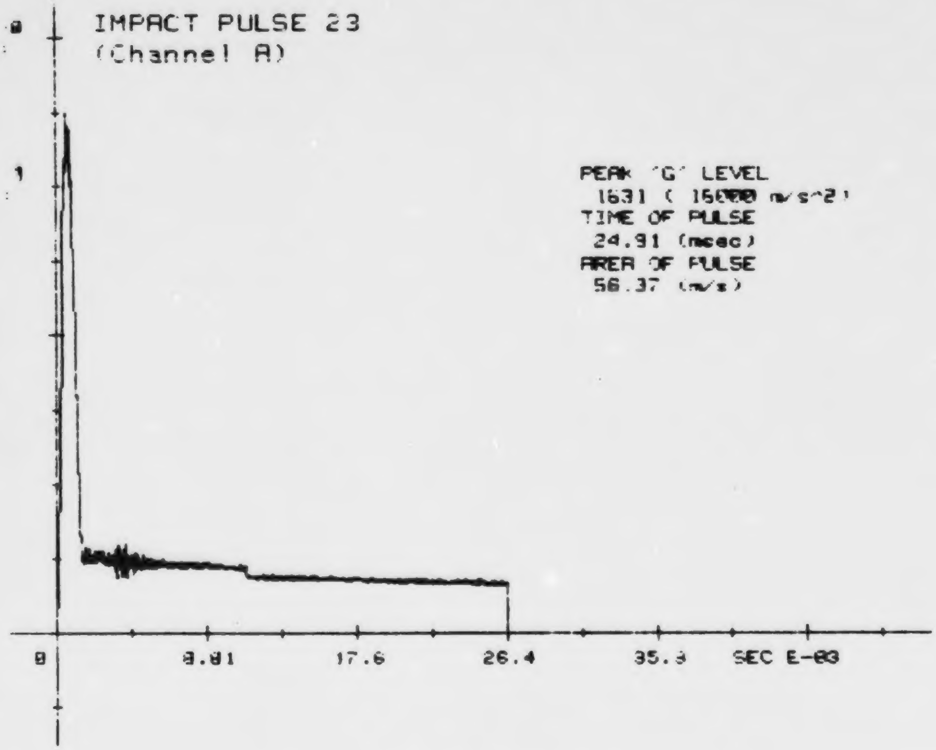
PEAK 'G' LEVEL
4027 (39500 m/s^2)
TIME OF PULSE
.3668 (msec)
AREA OF PULSE
6.521 (m/s)



PEAK 'G' LEVEL
4027 (39500 m/s^2)
TIME OF PULSE
.3668 (msec)
AREA OF PULSE
6.521 (m/s)

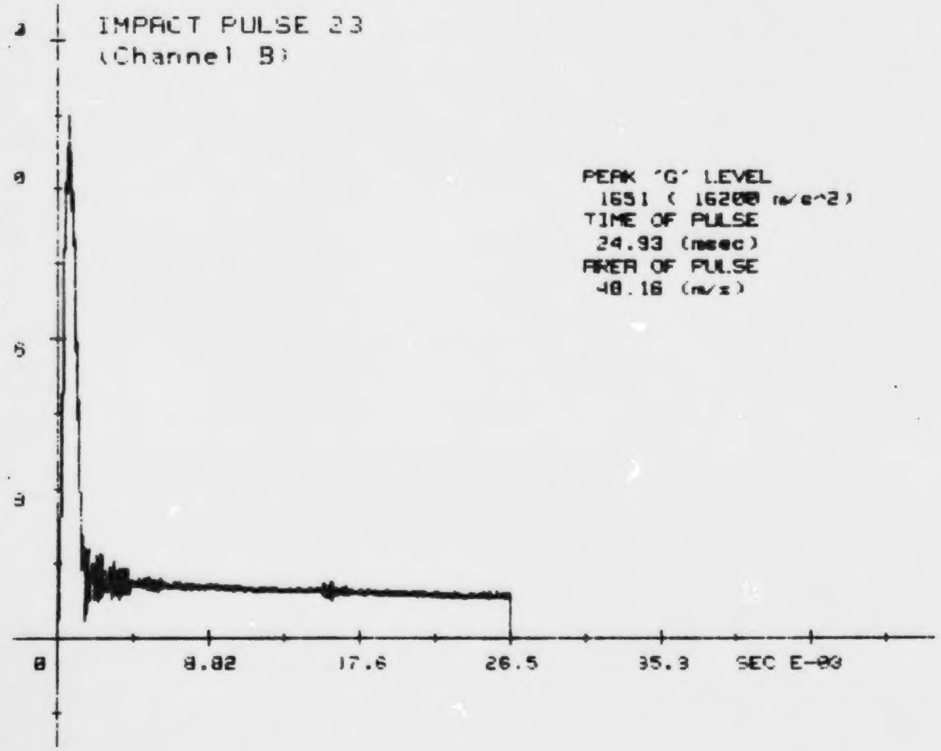
SIN FIT 'G' LEVEL
2847 (27930 m/s^2)
SIN FIT DURATION
.2593 (msec)
ALL CURVES HAVE SAME AREA

```
                TEST DATE          AUGUST 17 1984
                TEST NUMBER        23
-----------------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                              GE-327
BULB #1 AGE (Hours)                                 0
BULB #2 AGE (Hours)                                 48
BULB #3 AGE (Hours)                                 85
BULB #4 AGE (Hours)                                 144
IMPACT MEDIUM                                      WHITE PAD
TEST VOLTAGE                                       28
NUMBER OF SHOCK CORDS                               2
ACCELEROMETER (Channel A)                           827083
ACCELEROMETER (Channel B)                           827086
GAINS                                               1          1
3K FILTER BULB 3 BROKE ON SECOND BOUNCE



RESISTANCE...
               BEFORE         AFTER          DELTA
----------------------------------------------------------

BULB 1         79.648         79.508        -.14023
BULB 2         81.677         60.879        -20.798
BULB 3         72.187         99999          99927
BULB 4         71.559         61.286        -10.272



               DAMAGE REPORT --> TEST 23
NUMBER  DAMAGE         (Peak G-  1631  )
------------------------------------------------------------------------------

BULB 1    Gen. stretch
BULB 2    Gen. stretch Loc. stretch
BULB 3    Gen. stretch Loc. stretch
BULB 4    Gen. stretch Loc. stretch

COMMENTS...
BULB 1    SEM#266
BULB 2    APPEARED FRACTURE BUT SHORTED ITSELF OUT TO APPEAR FUNCTI
BULB 3    SEM#268
BULB 4    SEM#269
```



IMPACT PULSE 23
(Channel A)

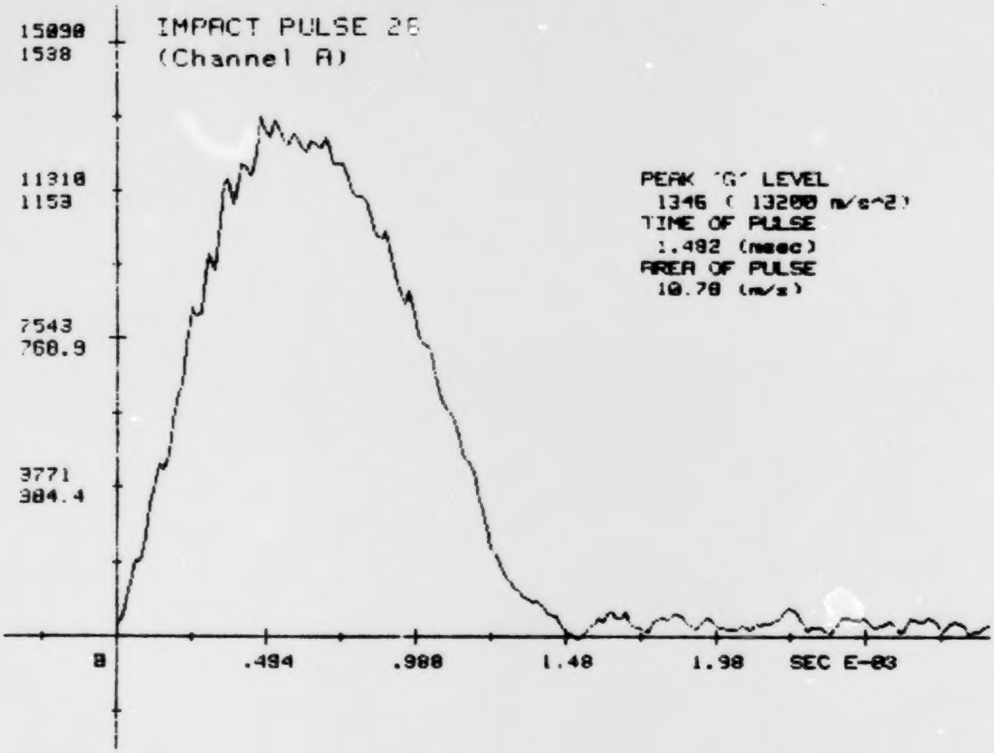
PEAK 'G' LEVEL
1631 (16000 m/s^2)
TIME OF PULSE
24.91 (msec)
AREA OF PULSE
56.37 (m/s)



IMPACT PULSE 23
(Channel B)

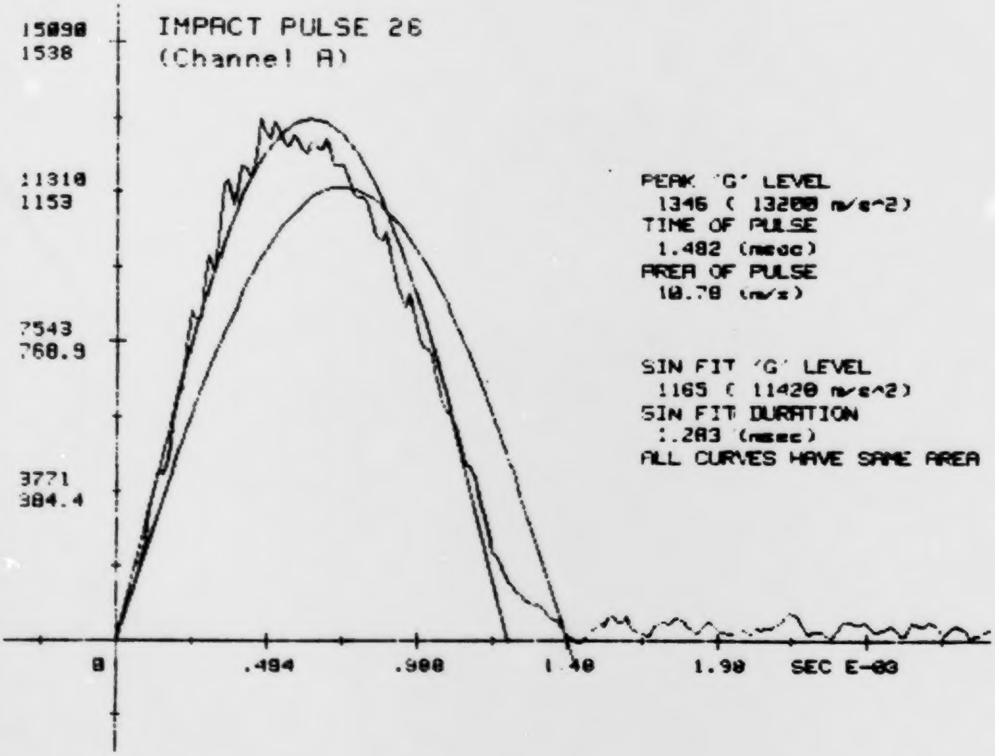
PEAK 'G' LEVEL
1651 (16200 m/s^2)
TIME OF PULSE
24.93 (msec)
AREA OF PULSE
48.16 (m/s)

```
              TEST DATE          AUGUST 20 1984
              TEST NUMBER        26
------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                    GE-327
BULB #1 AGE (Hours)                        210
BULB #2 AGE (Hours)                        250
BULB #3 AGE (Hours)                        210
BULB #4 AGE (Hours)                        250
IMPACT MEDIUM                            WHITE PAD
TEST VOLTAGE                               28
NUMBER OF SHOCK CORDS                      2
ACCELEROMETER (Channel A)                  827083
ACCELEROMETER (Channel B)                  827086
GAINS                                      1          1
3K FILTER -BULB 4 BRIGHTENED AFTER IMPACT



RESISTANCE...
             BEFORE        AFTER        DELTA
------------------------------------------------

BULB 1       77.766        62.969     -14.797
BULB 2       69.591        68.225     -1.3664
BULB 3       73.201        66.41      -6.7909
BULB 4       77.478        26.678     -50.799



                DAMAGE REPORT --> TEST 26
NUMBER  DAMAGE       (Peak G-  1386.3  )
------------------------------------------------------------

BULB 1   Gen. stretch
BULB 2   Gen. stretch
BULB 3   Gen. stretch Loc. stretch
BULB 4   Gen. stretch Loc. stretch

COMMENTS...
BULB 1   AGE LOOPS PRESENT
BULB 2   "    "    "
BULB 3   SHOWS DIRECTION OF IMPACT
BULB 4   FILAMENT TOUCHED TOGETHER IN CENTER AND SHORTED
```



IMPACT PULSE 26
(Channel A)

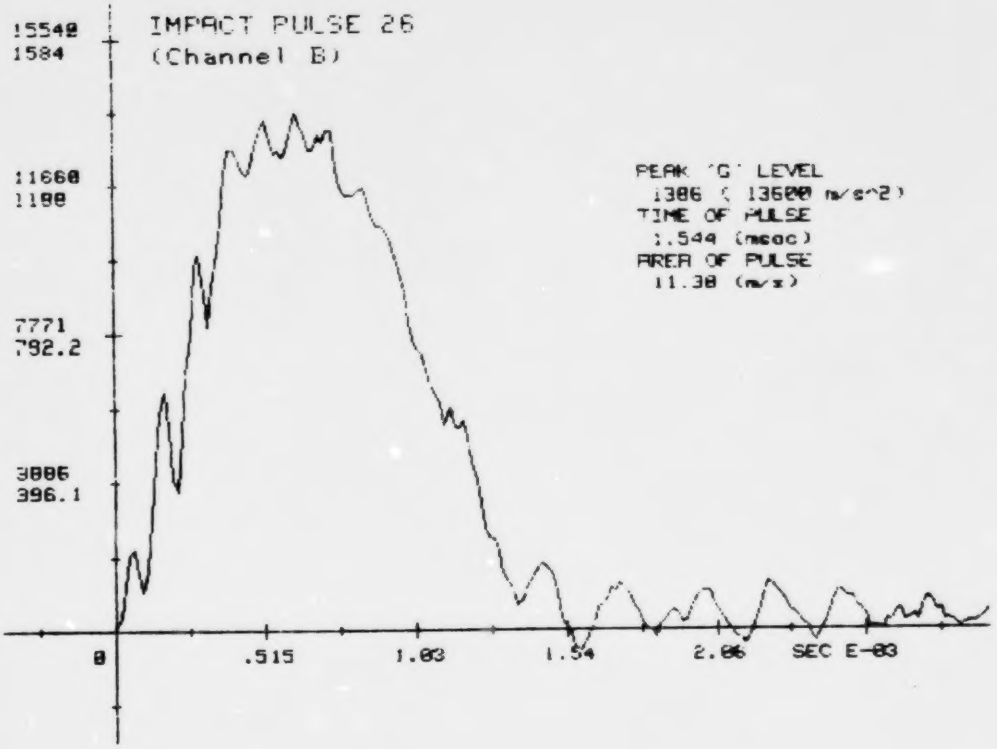
PEAK 'G' LEVEL
1346 (13200 m/s^2)
TIME OF PULSE
1.482 (msec)
AREA OF PULSE
10.78 (m/s)



IMPACT PULSE 26
(Channel A)

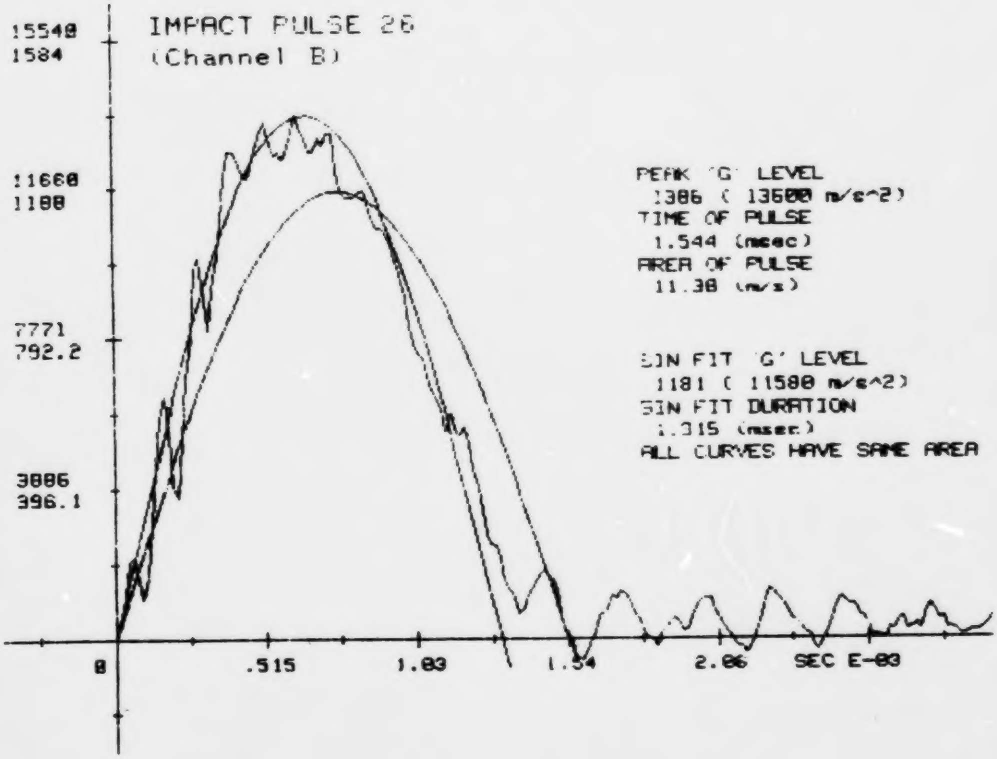
PEAK 'G' LEVEL
1346 (13200 m/s^2)
TIME OF PULSE
1.482 (msec)
AREA OF PULSE
10.78 (m/s)

SIN FIT 'G' LEVEL
1165 (11420 m/s^2)
SIN FIT DURATION
1.283 (msec)
ALL CURVES HAVE SAME AREA



IMPACT PULSE 26
(Channel B)

PEAK 'G' LEVEL
1386 (13600 m/s^2)
TIME OF PULSE
1.544 (msec)
AREA OF PULSE
11.30 (m/s)

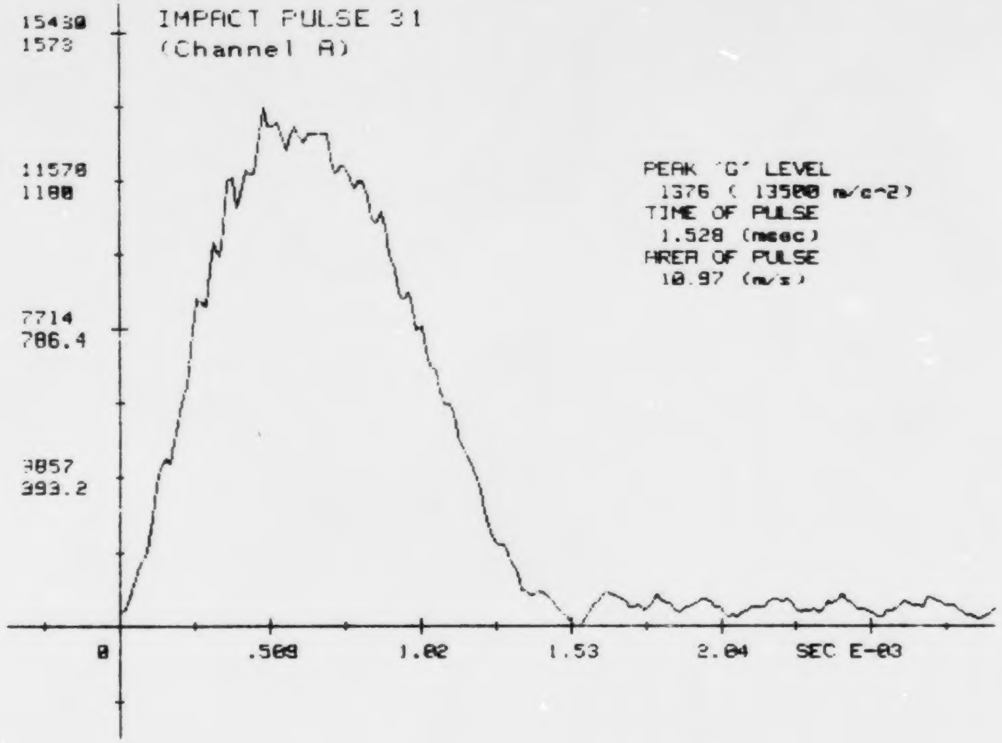


IMPACT PULSE 26
(Channel B)

PEAK 'G' LEVEL
1386 (13600 m/s^2)
TIME OF PULSE
1.544 (msec)
AREA OF PULSE
11.30 (m/s)

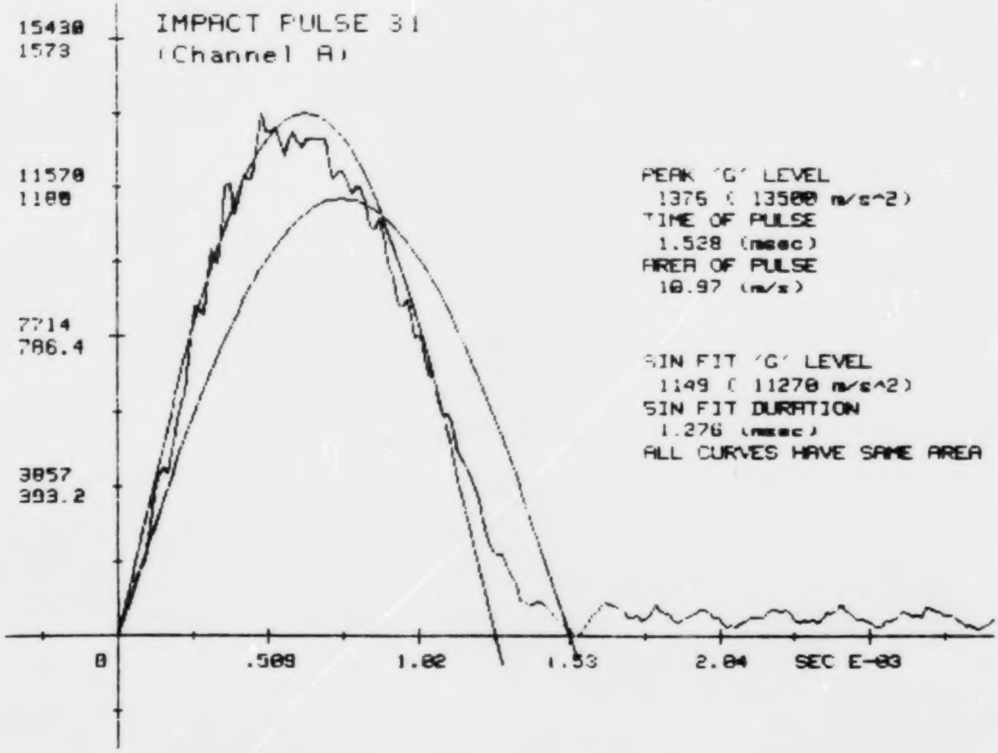
SIN FIT 'G' LEVEL
1181 (11580 m/s^2)
SIN FIT DURATION
1.315 (msec)
ALL CURVES HAVE SAME AREA

```
          TEST DATE          AUGUST 23 1984
          TEST NUMBER        31
-----------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                       GE-327
BULB #1 AGE (Hours)                          210
BULB #2 AGE (Hours)                          250
BULB #3 AGE (Hours)                          350
BULB #4 AGE (Hours)                          506
IMPACT MEDIUM                               WHITE PAD
TEST VOLTAGE                                0
NUMBER OF SHOCK CORDS                        2
ACCELEROMETER (Channel A)                    827083
ACCELEROMETER (Channel B)                    827086
GAINS                                        1         1
3K FILTER- BULB 2 RESISTANCE READING UNRELIABLE



RESISTANCE...
          BEFORE       AFTER        DELTA
-----------------------------------------------------

BULB 1      82.37        79.164     -3.2058
BULB 2      73.257       6.4E+14     6.4E+14
BULB 3      73.554       73.397     -.15692
BULB 4      82.916       99999       99916



          DAMAGE REPORT --> TEST 31
NUMBER  DAMAGE      (Peak G-  1376.1  )
-----------------------------------------------------------------

BULB 1   None
BULB 2   None
BULB 3   None
BULB 4   1-frac.

COMMENTS...
BULB 1
BULB 2
BULB 3
BULB 4   BETWEEN RIGHT SUPPORT AND RIGHT CONTACT POST
```



IMPACT PULSE 31
(Channel A)

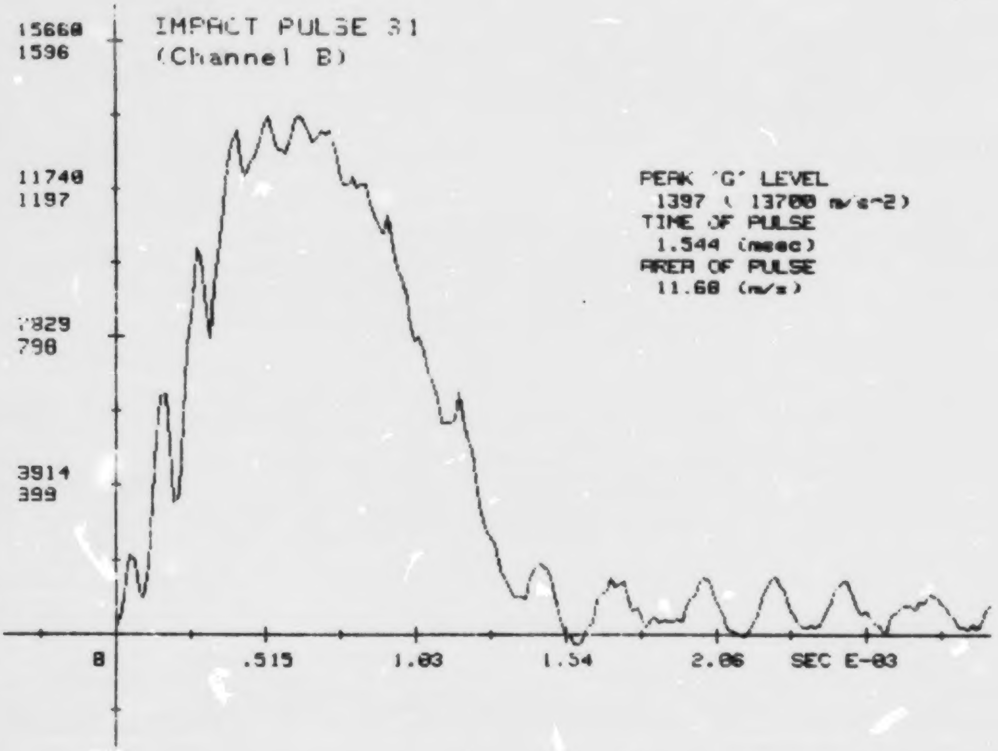
PEAK 'G' LEVEL
1376 (13500 m/s^2)
TIME OF PULSE
1.528 (msec)
AREA OF PULSE
10.97 (m/s)

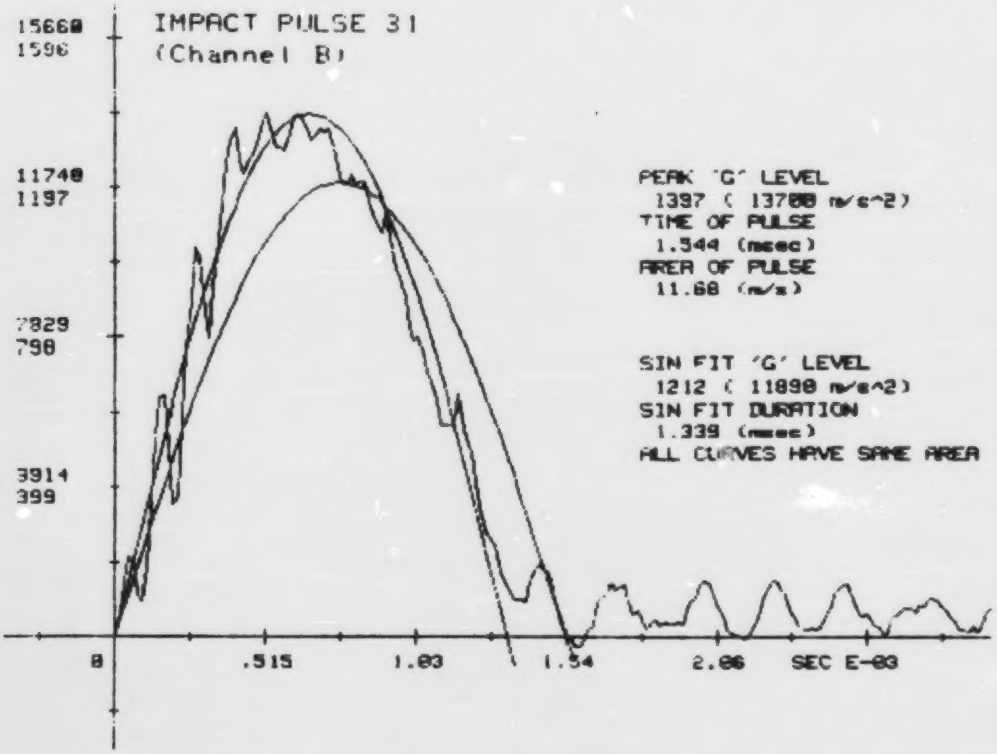


IMPACT PULSE 31
(Channel A)

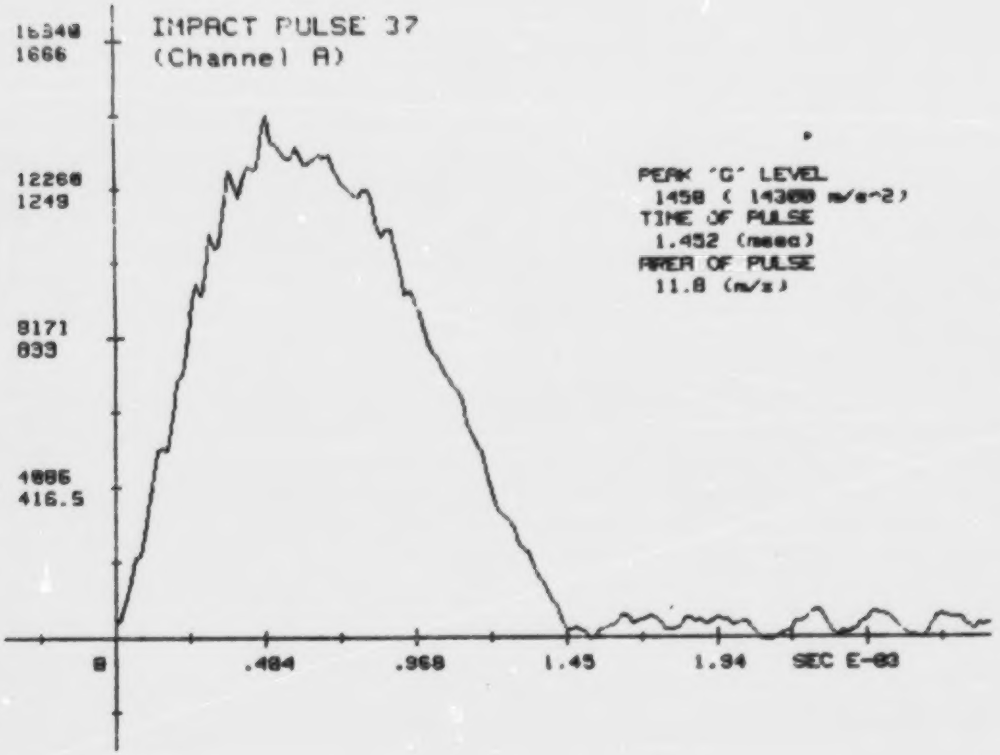
PEAK 'G' LEVEL
1376 (13500 m/s^2)
TIME OF PULSE
1.528 (msec)
AREA OF PULSE
10.97 (m/s)

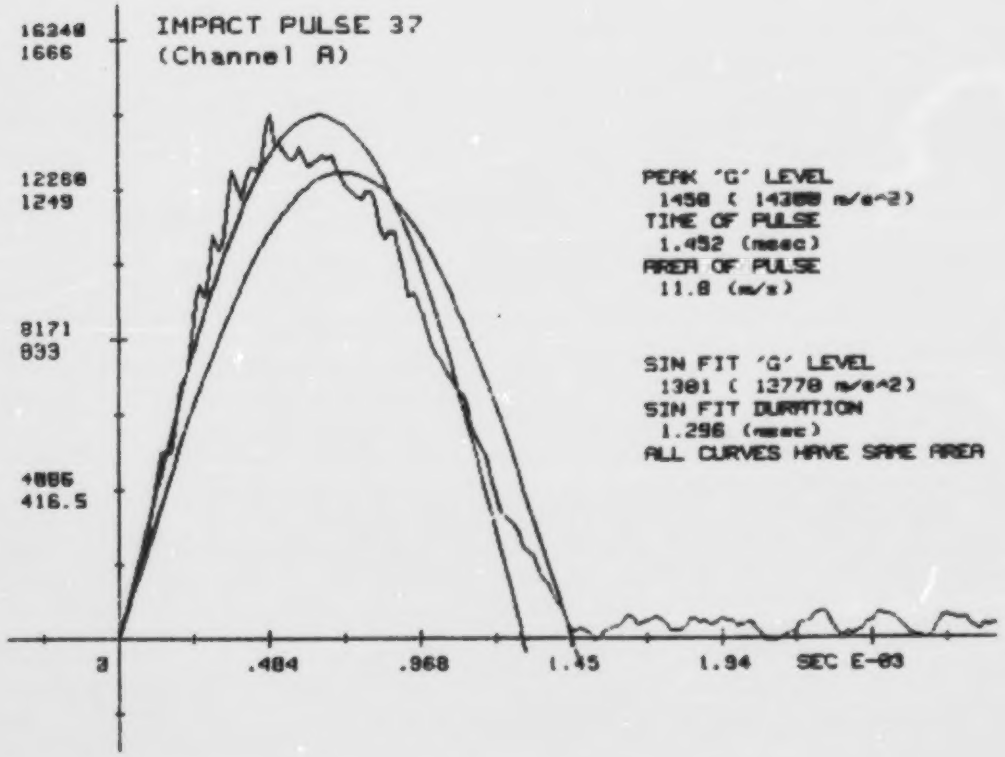
SIN FIT 'G' LEVEL
1149 (11270 m/s^2)
SIN FIT DURATION
1.276 (msec)
ALL CURVES HAVE SAME AREA

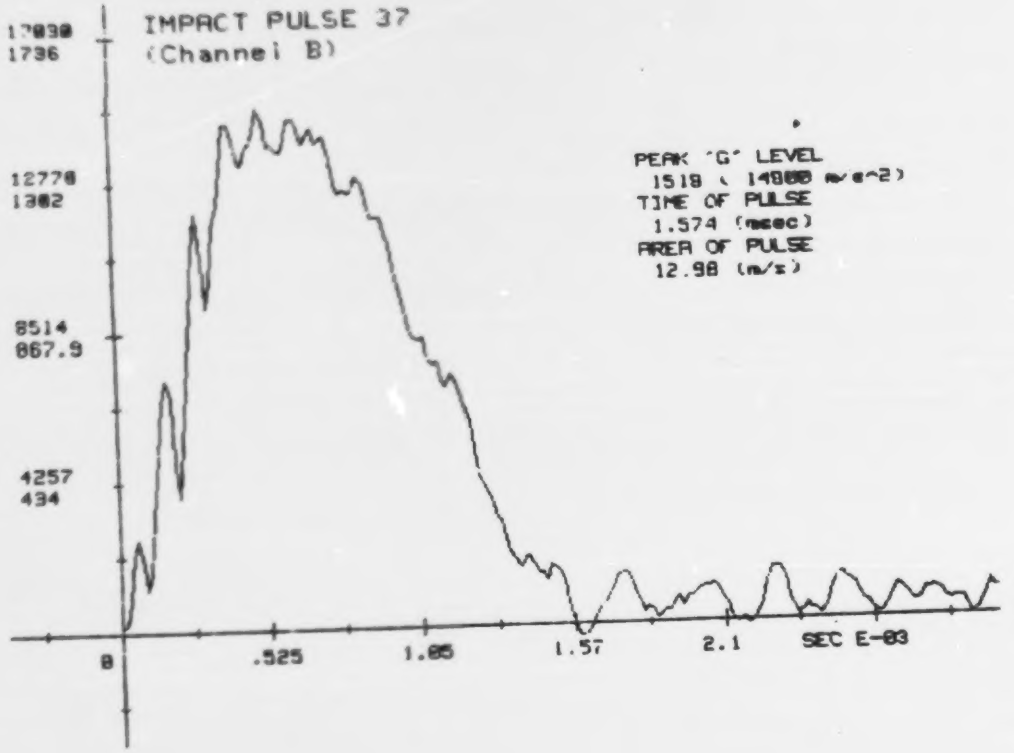

IMPACT PULSE 31
(Channel B)
15660
1596
11740
1197
7829
798
3914
399
0
.515
1.03
1.54
2.06
SEC E-03
PEAK 'G' LEVEL
1397 (13700 m/s^2)
TIME OF PULSE
1.544 (msec)
AREA OF PULSE
11.60 (m/s)


IMPACT PULSE 31
(Channel B)
15660
1596
11740
1197
7829
798
3914
399
0
.515
1.03
1.54
2.06
SEC E-03
PEAK 'G' LEVEL
1397 (13700 m/s^2)
TIME OF PULSE
1.544 (msec)
AREA OF PULSE
11.60 (m/s)
SIN FIT 'G' LEVEL
1212 (11890 m/s^2)
SIN FIT DURATION
1.339 (msec)
ALL CURVES HAVE SAME AREA

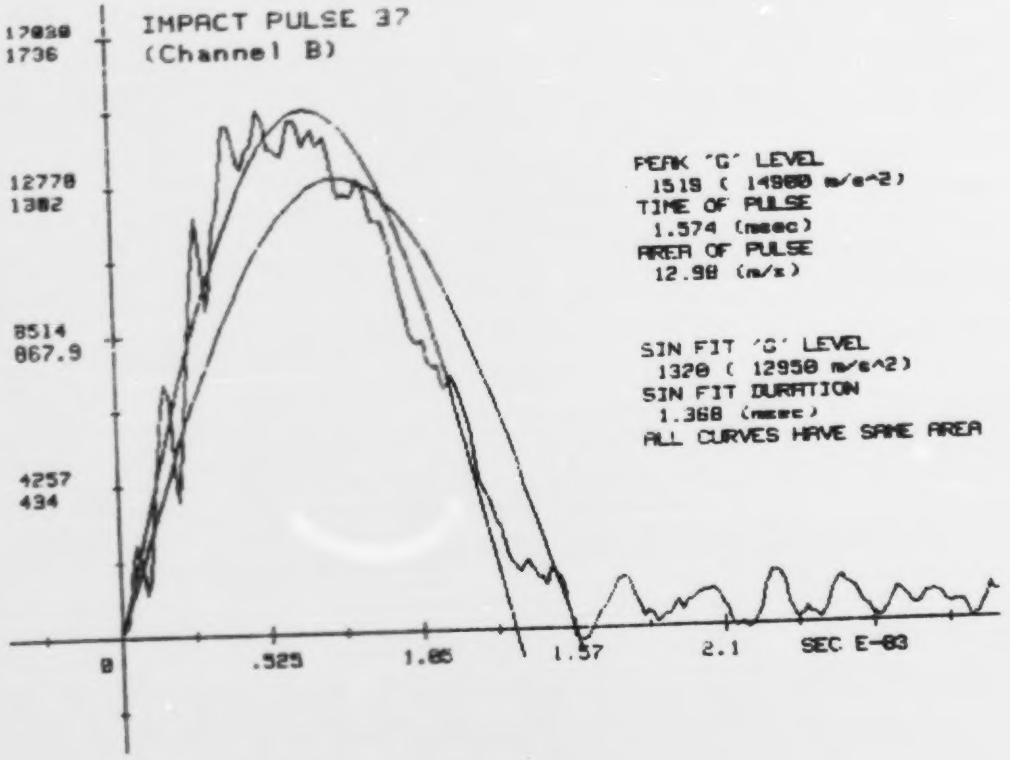
```
          TEST DATE          AUGUST 27 1984
          TEST NUMBER        37
-----------------------------------------------------------

BULB TYPE ( 4 -BULBS)                   GE-327
BULB #1 AGE (Hours)                      0
BULB #2 AGE (Hours)                      48
BULB #3 AGE (Hours)                      85
BULB #4 AGE (Hours)                      144
IMPACT MEDIUM                           WHITE PAD
TEST VOLTAGE                            28
NUMBER OF SHOCK CORDS                    4
ACCELEROMETER (Channel A)                827083
ACCELEROMETER (Channel B)                827086
GAINS                                    1         1
3K FILTER -NONE BROKE



RESISTANCE...
            BEFORE      AFTER       DELTA
------------------------------------------------

BULB 1       78.104      77.907    -.19694
BULB 2       73.325      59.643    -13.683
BULB 3       75.031      67.607    -7.4237
BULB 4       73.558      24.162    -49.396



            DAMAGE REPORT --> TEST 37
NUMBER   DAMAGE       (Peak G-   1518.9   )
----------------------------------------------------------------

BULB 1   Gen. stretch
BULB 2   Gen. stretch Loc. stretch
BULB 3   Gen. stretch Loc. stretch
BULB 4   Gen. stretch Loc. stretch

COMMENTS...
BULB 1   SLIGHT GENERAL STRETCH IN IMPACT DIRECTION
BULB 2   SHOWS DIRECTION WELL
BULB 3   SHOWS DIRECTION AND STRETCHED TO GLASS ENVELOPE
BULB 4   FILAMENT NOT QUITE TOUCHING TOGETHER IN CENTER-may have b
```


IMPACT PULSE 37
(Channel A)
16240
1666
12260
1249
8171
833
4086
416.5
0
.484
.968
1.45
1.94
SEC E-03
PEAK 'G' LEVEL
1450 (14300 m/s^2)
TIME OF PULSE
1.452 (msec)
AREA OF PULSE
11.8 (m/s)


IMPACT PULSE 37
(Channel A)
16240
1666
12260
1249
8171
833
4086
416.5
0
.484
.968
1.45
1.94
SEC E-03
PEAK 'G' LEVEL
1450 (14300 m/s^2)
TIME OF PULSE
1.452 (msec)
AREA OF PULSE
11.8 (m/s)
SIN FIT 'G' LEVEL
1301 (12770 m/s^2)
SIN FIT DURATION
1.296 (msec)
ALL CURVES HAVE SAME AREA



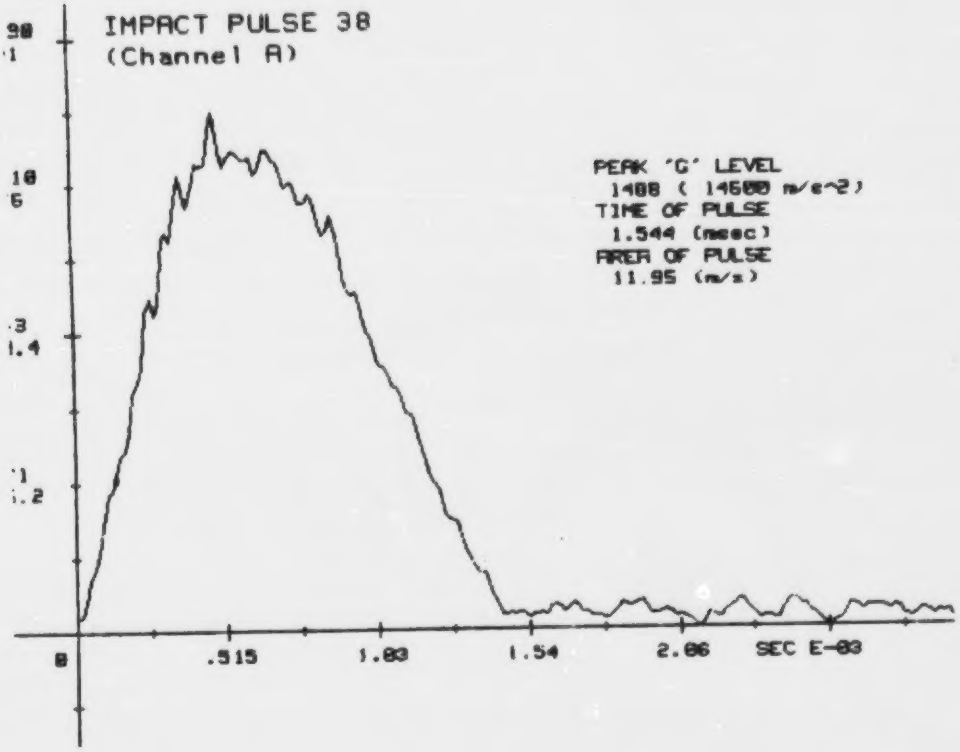
PEAK 'G' LEVEL
1519 (14900 m/s^2)
TIME OF PULSE
1.574 (msec)
AREA OF PULSE
12.90 (m/s)



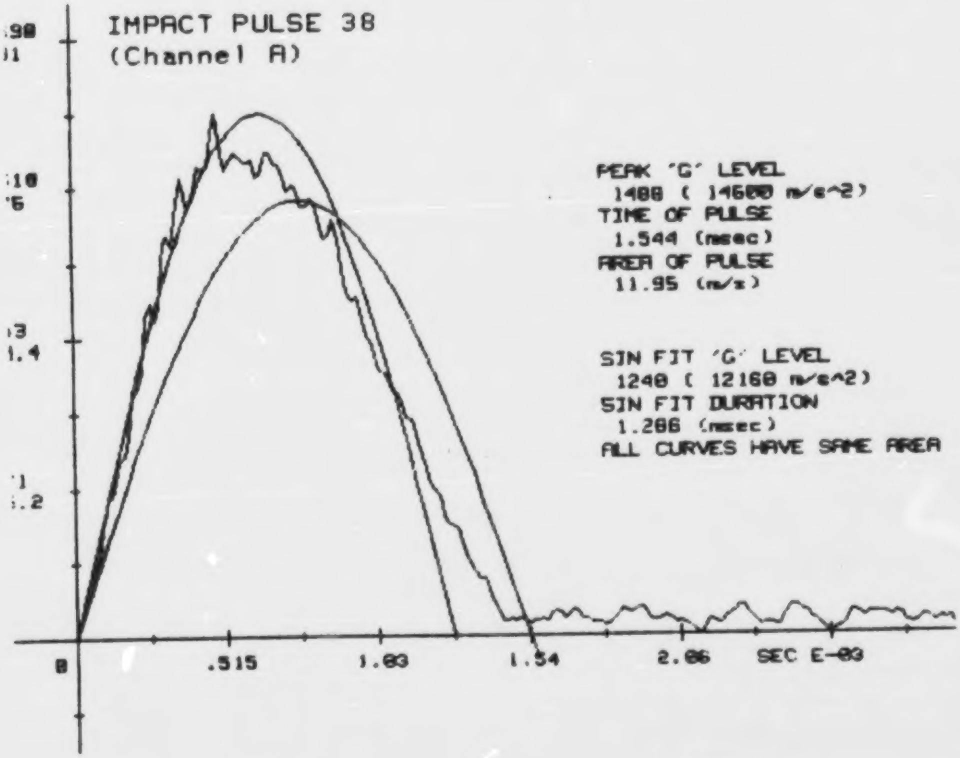
PEAK 'G' LEVEL
1519 (14900 m/s^2)
TIME OF PULSE
1.574 (msec)
AREA OF PULSE
12.90 (m/s)

SIN FIT 'G' LEVEL
1320 (12950 m/s^2)
SIN FIT DURATION
1.368 (msec)
ALL CURVES HAVE SAME AREA

```
          TEST DATE          AUGUST 27 1984
          TEST NUMBER        38
--------------------------------------------------------

BULB TYPE ( 4 -BULBS)                    GE-327
BULB #1 AGE (Hours)                       0
BULB #2 AGE (Hours)                       48
BULB #3 AGE (Hours)                       85
BULB #4 AGE (Hours)                       144
IMPACT MEDIUM                            WHITE PAD
TEST VOLTAGE                             0
NUMBER OF SHOCK CORDS                     4
ACCELEROMETER (Channel A)                 827083
ACCELEROMETER (Channel B)                 827086
GAINS                                     1        1
3K FILTER



RESISTANCE...
           BEFORE        AFTER        DELTA
----------------------------------------------

BULB 1      69.748        69.268     -.47999
BULB 2      71.931        99999       99927
BULB 3      77.796        75.911     -1.8853
BULB 4      64.56         64.815      .25493



            DAMAGE REPORT --> TEST 38
NUMBER  DAMAGE       (Peak G-  1569.8  )
------------------------------------------------------------

BULB 1   None
BULB 2   1-frac.
BULB 3   None
BULB 4   None

COMMENTS...
BULB 1   -
BULB 2   FRACTURE TOP DEAD CENTER
BULB 3   -
BULB 4   -
```

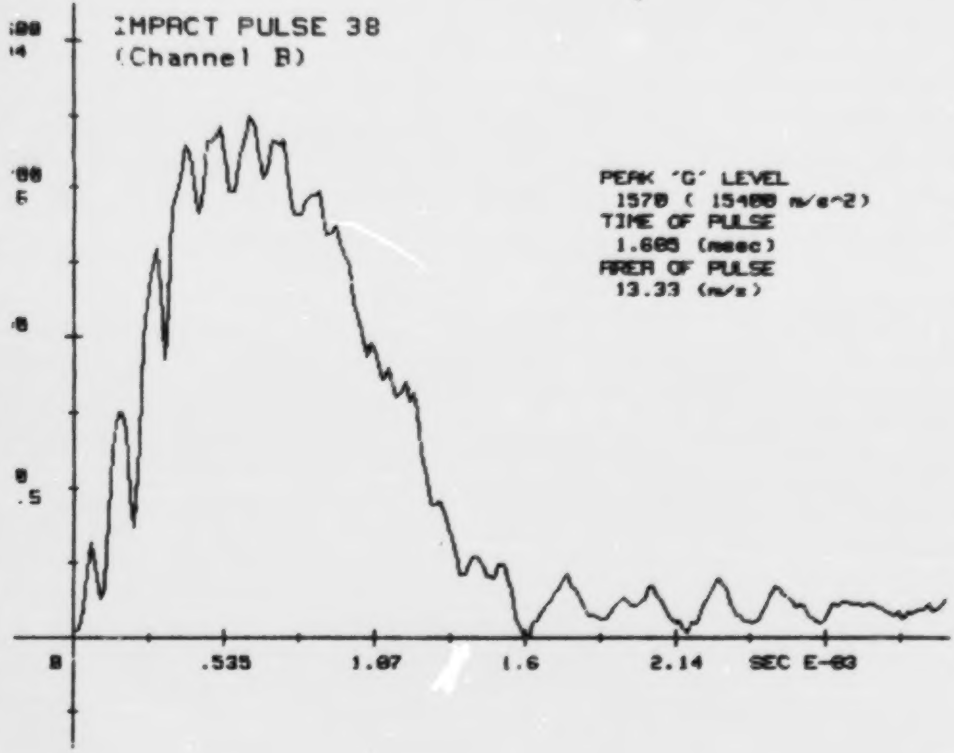


PEAK 'G' LEVEL
1400 (14600 m/s^2)
TIME OF PULSE
1.544 (msec)
AREA OF PULSE
11.95 (m/s)



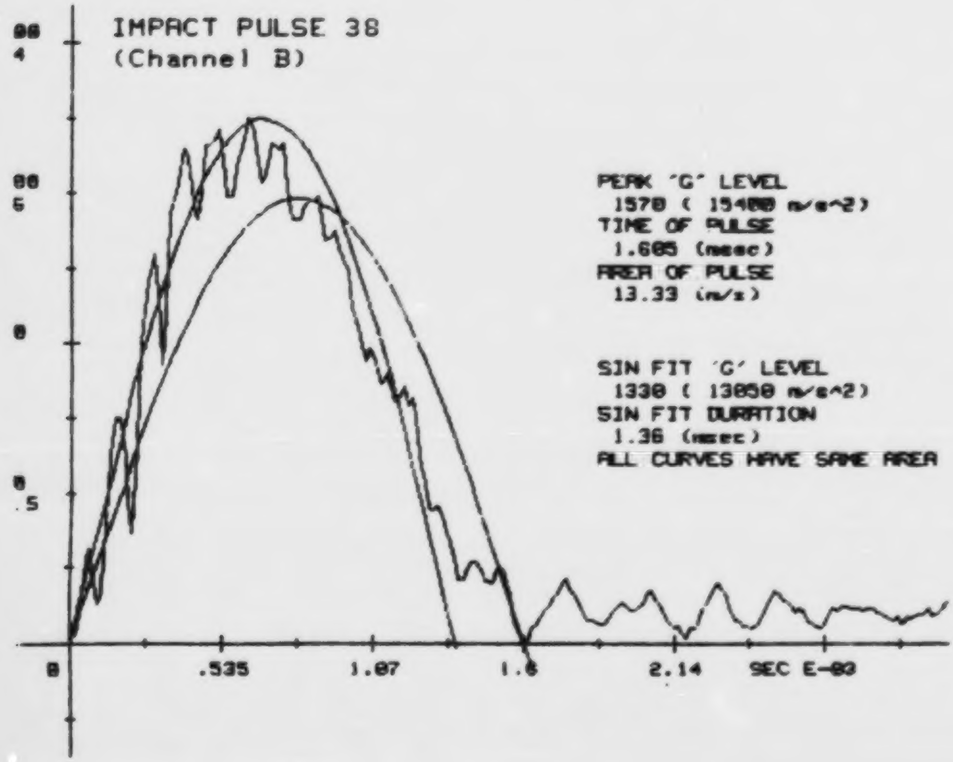
PEAK 'G' LEVEL
1400 (14600 m/s^2)
TIME OF PULSE
1.544 (msec)
AREA OF PULSE
11.95 (m/s)

SIN FIT 'G' LEVEL
1240 (12160 m/s^2)
SIN FIT DURATION
1.286 (msec)
ALL CURVES HAVE SAME AREA



IMPACT PULSE 38
(Channel B)

PEAK 'G' LEVEL
1570 (15400 m/s^2)
TIME OF PULSE
1.605 (msec)
AREA OF PULSE
13.33 (m/s)

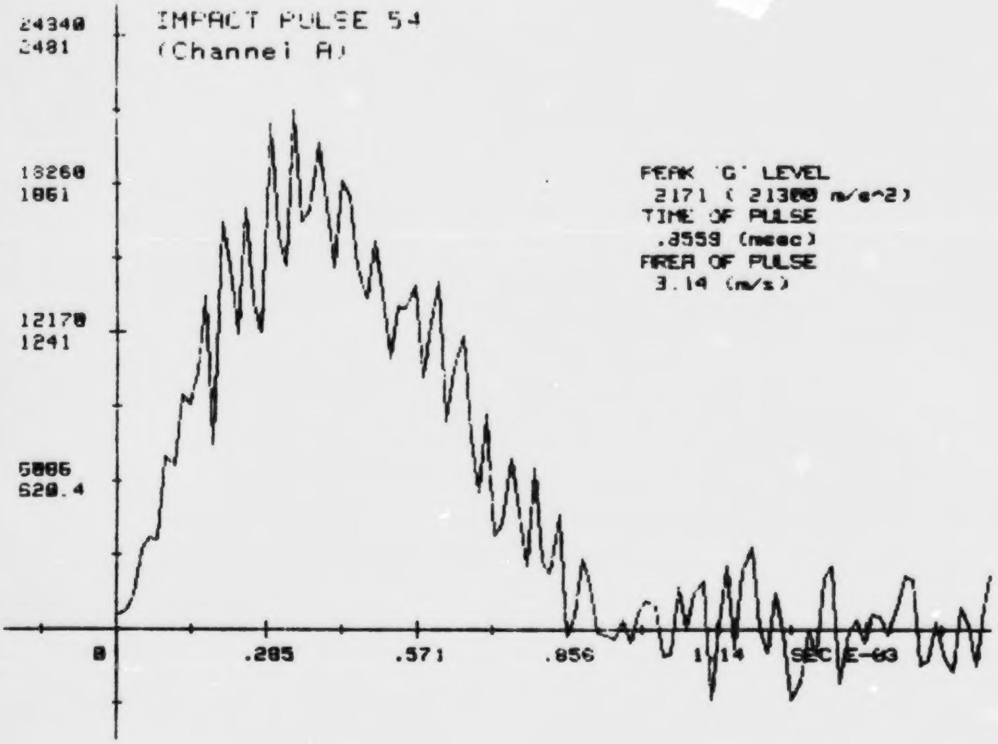


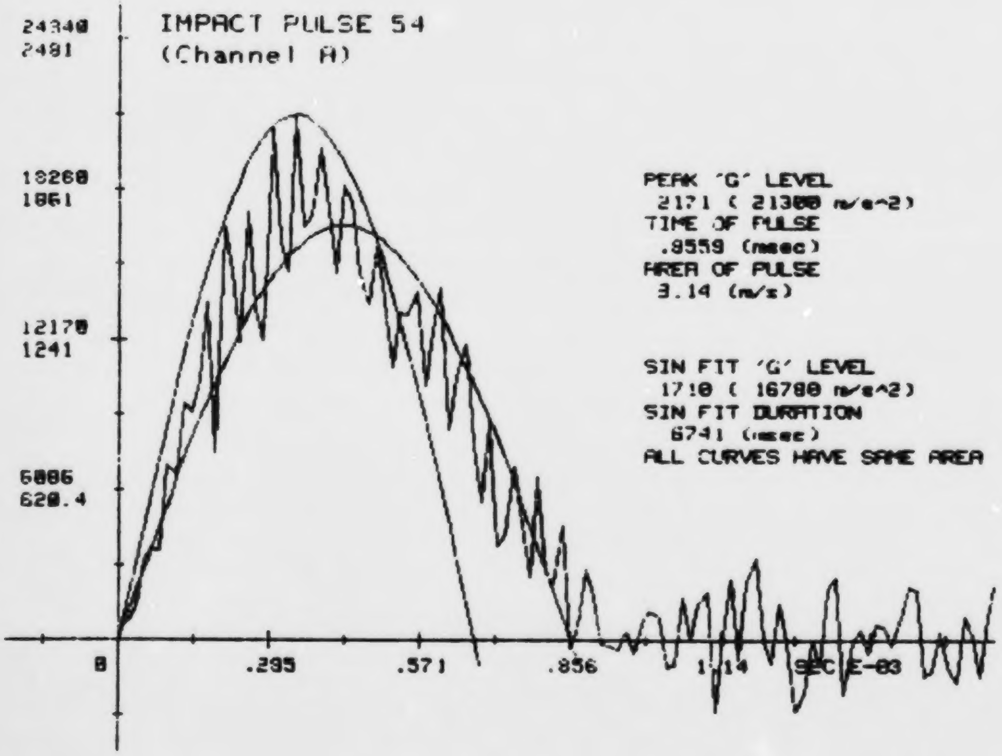
IMPACT PULSE 38
(Channel B)

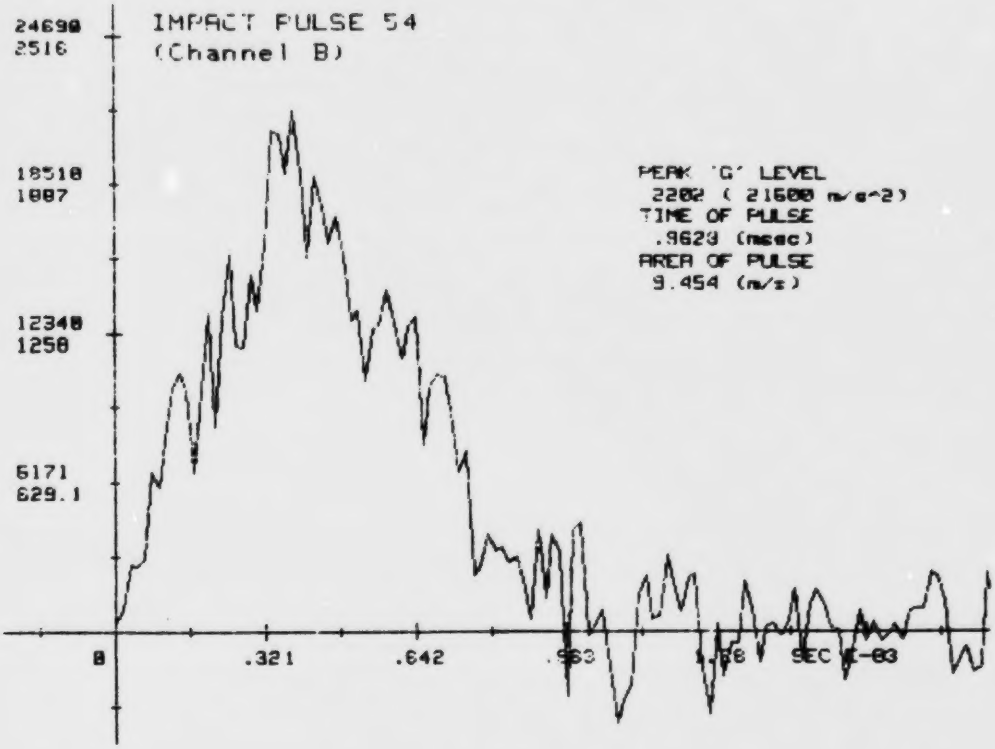
PEAK 'G' LEVEL
1570 (15400 m/s^2)
TIME OF PULSE
1.605 (msec)
AREA OF PULSE
13.33 (m/s)

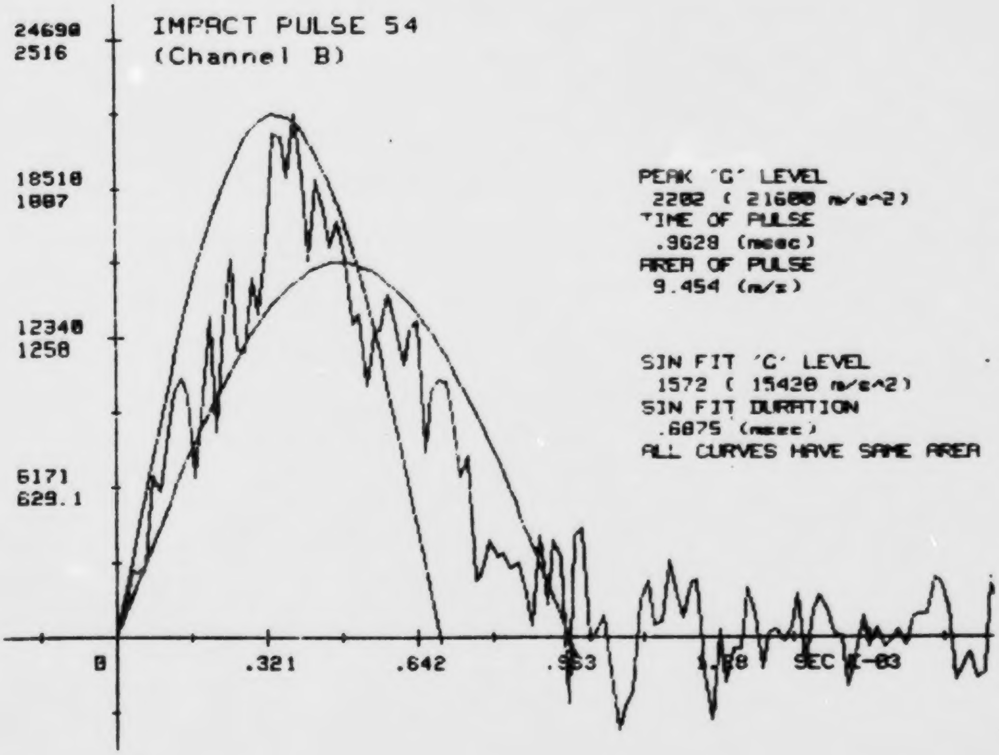
SIN FIT 'G' LEVEL
1330 (13050 m/s^2)
SIN FIT DURATION
1.36 (msec)
ALL CURVES HAVE SAME AREA

```
                TEST DATE           SEPT 10 1984
                TEST NUMBER         54
------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                          GE-327
BULB #1 AGE (Hours)                             0
BULB #2 AGE (Hours)                             48
BULB #3 AGE (Hours)                             85
BULB #4 AGE (Hours)                             144
IMPACT MEDIUM                                  WHITE PAD 1/2
TEST VOLTAGE                                   28
NUMBER OF SHOCK CORDS                          0
ACCELEROMETER (Channel A)                       827083
ACCELEROMETER (Channel B)                       827086
GAINS                                           1          1
10K FILTER- BULB 4 WENT OUT



RESISTANCE...
            BEFORE        AFTER         DELTA
-------------------------------------------------

BULB 1       77.784        73.099       -4.6853
BULB 2       76.41         65.452       -10.958
BULB 3       71.848        24.458       -47.389
BULB 4       70.459        99999         99929



              DAMAGE REPORT --> TEST 54
NUMBER  DAMAGE      (Peak G-  2201.8  )
------------------------------------------------------------

BULB 1   Gen. stretch
BULB 2   Gen. stretch Loc. stretch
BULB 3   Gen. stretch Loc. stretch
BULB 4   Gen. stretch Loc. stretch 1-frac.

COMMENTS...
BULB 1   SLIGHT GENERAL STRETCH
BULB 2   SHOWS IMPACT DIRECTION
BULB 3   FILAMENT TOUCHED TOGETHER IN CENTER
BULB 4   MIDWAY RIGHT SUPPORT AND RIGHT CONTACT POST -SNAKING EVID
```

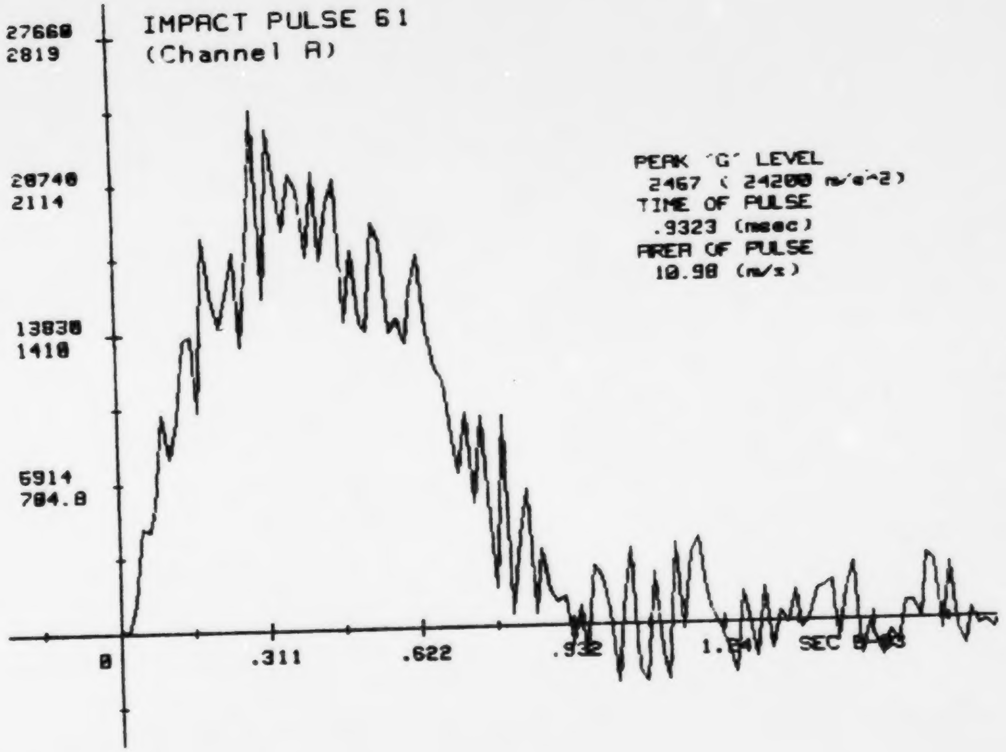

IMPACT PULSE 54
(Channel A)
24340
2481
18260
1861
12170
1241
6086
620.4
0
.285
.571
.856
1.14
SEC E-03
PEAK 'G' LEVEL
2171 (21300 m/s^2)
TIME OF PULSE
.8559 (msec)
AREA OF PULSE
3.14 (m/s)


IMPACT PULSE 54
(Channel A)
24340
2481
18260
1861
12170
1241
6086
620.4
0
.285
.571
.856
1.14
SEC E-03
PEAK 'G' LEVEL
2171 (21300 m/s^2)
TIME OF PULSE
.8559 (msec)
AREA OF PULSE
3.14 (m/s)
SIN FIT 'G' LEVEL
1710 (16780 m/s^2)
SIN FIT DURATION
.6741 (msec)
ALL CURVES HAVE SAME AREA


IMPACT PULSE 54
(Channel B)
24690
2516
18510
1887
12340
1258
6171
629.1
0
.321
.642
.963
1.28
SEC E-03
PEAK 'G' LEVEL
2202 (21600 m/s^2)
TIME OF PULSE
.9628 (msec)
AREA OF PULSE
9.454 (m/s)

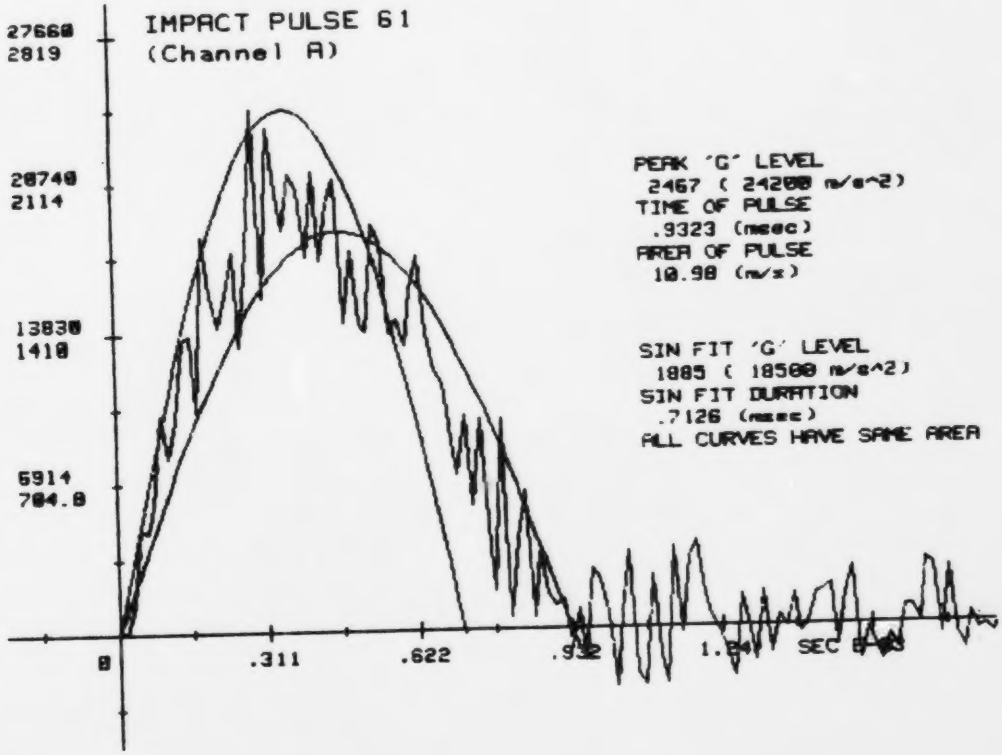

IMPACT PULSE 54
(Channel B)
24690
2516
18510
1887
12340
1258
6171
629.1
0
.321
.642
.963
1.28
SEC E-03
PEAK 'G' LEVEL
2202 (21600 m/s^2)
TIME OF PULSE
.9628 (msec)
AREA OF PULSE
9.454 (m/s)
SIN FIT 'G' LEVEL
1572 (15420 m/s^2)
SIN FIT DURATION
.6875 (msec)
ALL CURVES HAVE SAME AREA

```
                TEST DATE          SEPT 11 1984
                TEST NUMBER        61
----------------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                              GE-327
BULB #1 AGE (Hours)                                 0
BULB #2 AGE (Hours)                                 48
BULB #3 AGE (Hours)                                 85
BULB #4 AGE (Hours)                                 144
IMPACT MEDIUM                                      WHITE PAD A
TEST VOLTAGE                                       28
NUMBER OF SHOCK CORDS                               2
ACCELEROMETER (Channel A)                           827083
ACCELEROMETER (Channel B)                           827086
GAINS                                               1          1
10K FILTER- BULB 4 WENT OUT



RESISTANCE...
               BEFORE        AFTER         DELTA
-------------------------------------------------------

BULB 1          73.56          72.348     -1.2118
BULB 2          70.26          24.158     -46.102
BULB 3          80.463         60.141     -20.322
BULB 4          73.156         99999       99926



                 DAMAGE REPORT --> TEST 61
NUMBER  DAMAGE       (Peak G-  2742.1  )
---------------------------------------------------------------------------

BULB 1   Gen. stretch
BULB 2   Gen. stretch Loc. stretch
BULB 3   Gen. stretch Loc. stretch
BULB 4   Gen. stretch Loc. stretch 1-frac.

COMMENTS...
BULB 1   SHOWS IMPACT DIRECTION
BULB 2   FILAMENT CROSSED IN CENTER
BULB 3   SHOWS IMPACT DIRECTION WELL
BULB 4   FRACTURE NEAR LEFT CONTACT
```



IMPACT PULSE 61
(Channel A)

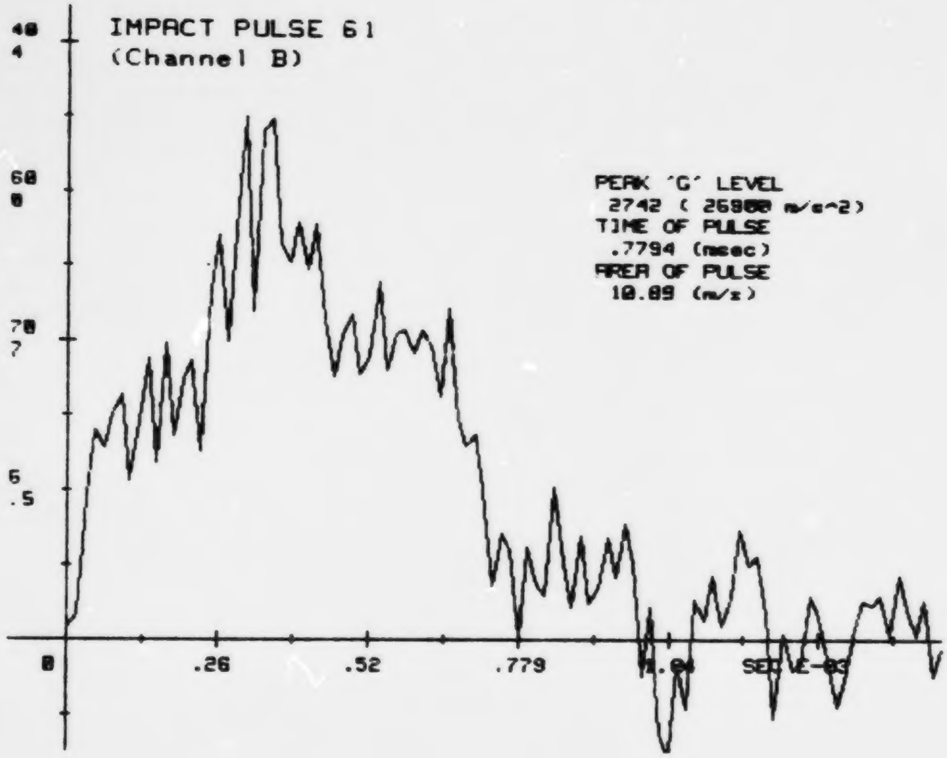
PEAK 'G' LEVEL
2467 (24200 m/s^2)
TIME OF PULSE
.9323 (msec)
AREA OF PULSE
10.98 (m/s)

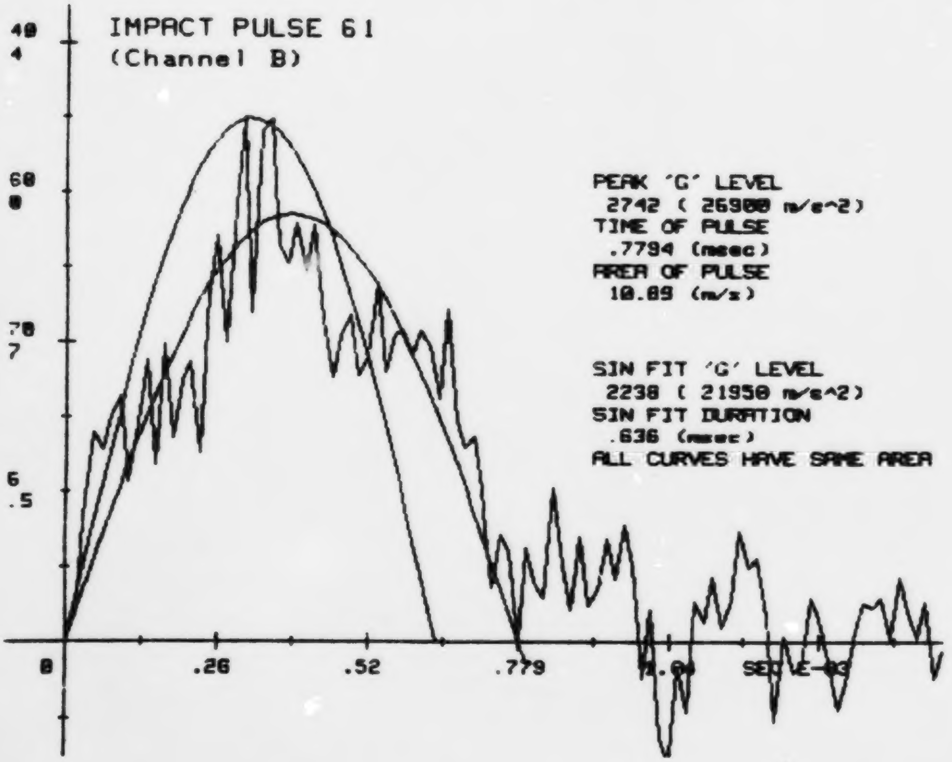


IMPACT PULSE 61
(Channel A)

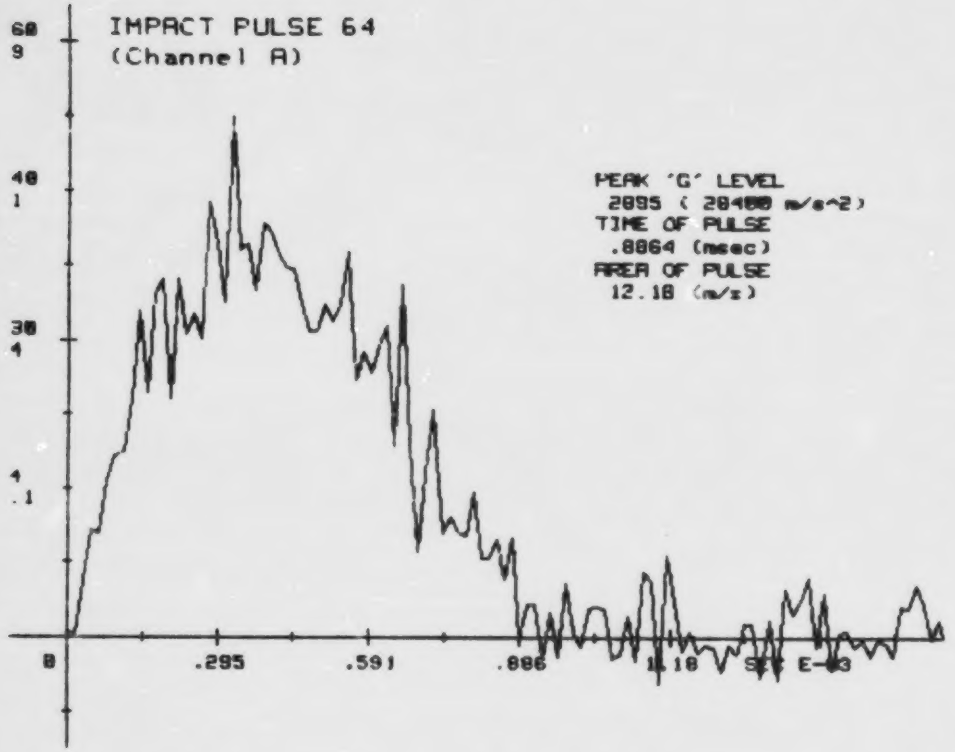
PEAK 'G' LEVEL
2467 (24200 m/s^2)
TIME OF PULSE
.9323 (msec)
AREA OF PULSE
10.98 (m/s)

SIN FIT 'G' LEVEL
1885 (18500 m/s^2)
SIN FIT DURATION
.7126 (msec)
ALL CURVES HAVE SAME AREA

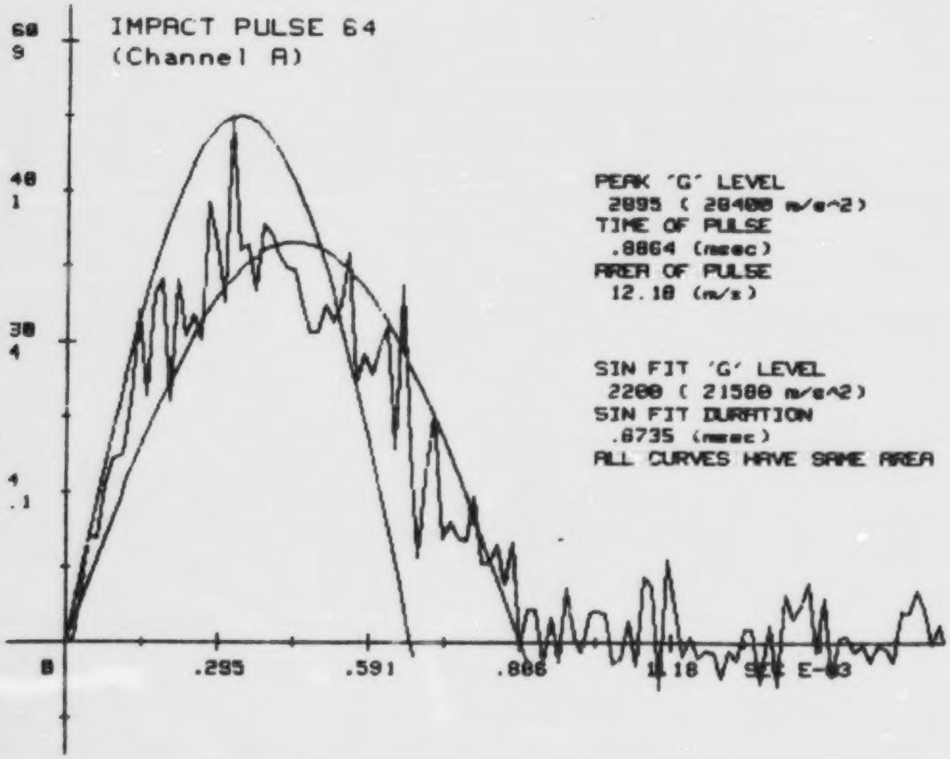

IMPACT PULSE 61
(Channel B)
40
4
60
0
70
7
6
.5
0
.26
.52
.779
1.04
SEC E-03
PEAK 'G' LEVEL
2742 (26900 m/s^2)
TIME OF PULSE
.7794 (msec)
AREA OF PULSE
10.89 (m/s)


IMPACT PULSE 61
(Channel B)
40
4
60
0
70
7
6
.5
0
.26
.52
.779
1.04
SEC E-03
PEAK 'G' LEVEL
2742 (26900 m/s^2)
TIME OF PULSE
.7794 (msec)
AREA OF PULSE
10.89 (m/s)
SIN FIT 'G' LEVEL
2238 (21950 m/s^2)
SIN FIT DURATION
.636 (msec)
ALL CURVES HAVE SAME AREA

```
          TEST DATE          SEPT 12 1984
          TEST NUMBER        64
     ----------------------------------------------------------

     BULB TYPE ( 4 -BULBS)                      GE-327
     BULB #1 AGE (Hours)                         0
     BULB #2 AGE (Hours)                         48
     BULB #3 AGE (Hours)                         85
     BULB #4 AGE (Hours)                         144
     IMPACT MEDIUM                              WHITE PAD A
     TEST VOLTAGE                               28
     NUMBER OF SHOCK CORDS                       4
     ACCELEROMETER (Channel A)                   827083
     ACCELEROMETER (Channel B)                   827086
     GAINS                                       1          1
     10K FILTER- BULB 4 WENT OUT




     RESISTANCE...
                 BEFORE        AFTER         DELTA
     -----------------------------------------------

     BULB 1       79.044        36.445     -42.599
     BULB 2       79.706        31.236     -48.47
     BULB 3       73.497        49.241     -24.255
     BULB 4       66.834        99999       99932



                  DAMAGE REPORT --> TEST 64
     NUMBER  DAMAGE       (Peak G-  3506.6  )
     ----------------------------------------------------------------

     BULB 1   Gen. stretch
     BULB 2   Gen. stretch Loc. stretch
     BULB 3   Gen. stretch Loc. stretch
     BULB 4   Gen. stretch Loc. stretch 2-frac.

     COMMENTS...
     BULB 1   SEVERE GENERAL STRETCH
     BULB 2   FILAMENT TOUCHED TOGETHER IN CENTER
     BULB 3   RANDOM STRETCH  FILAMENT MAY BE CROSSED NEAR RIGHT SUPPOR
     BULB 4   SEVERE STRECTH...BROKEN AT BOTH CONTACT POSTS
```

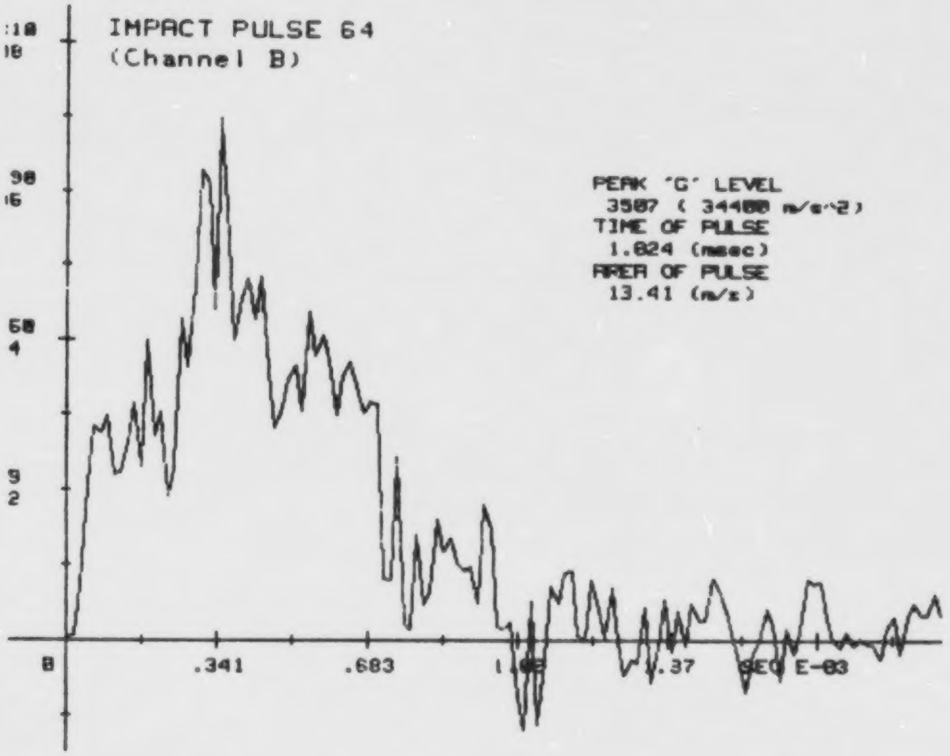


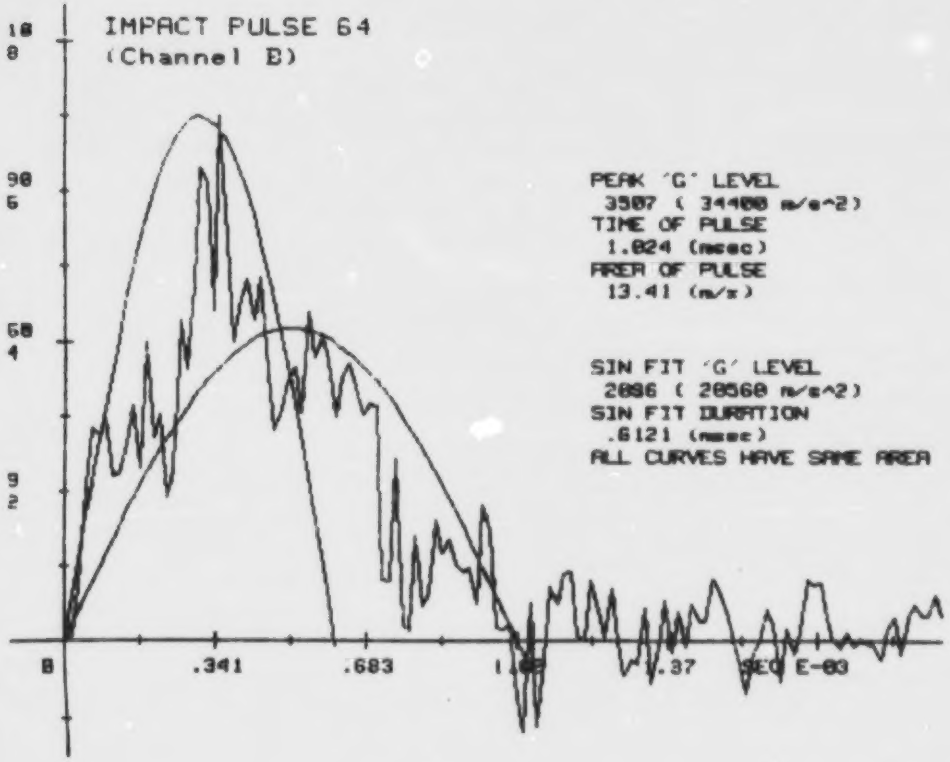
PEAK 'G' LEVEL
2895 (28400 m/s^2)
TIME OF PULSE
.0864 (msec)
AREA OF PULSE
12.10 (m/s)



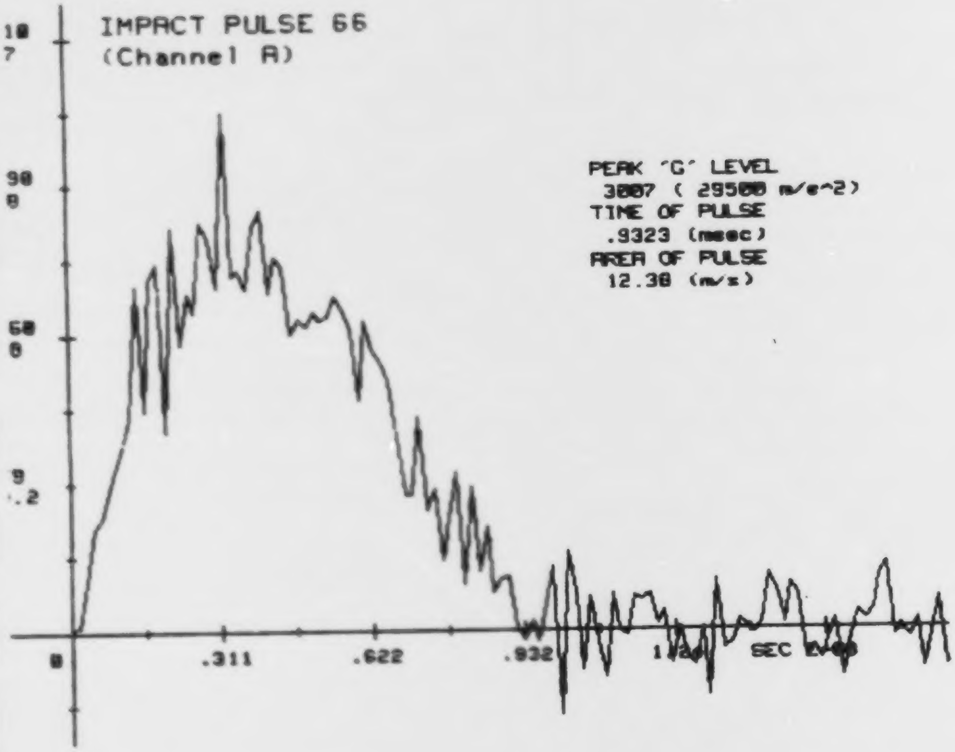
PEAK 'G' LEVEL
2895 (28400 m/s^2)
TIME OF PULSE
.0864 (msec)
AREA OF PULSE
12.10 (m/s)

SIN FIT 'G' LEVEL
2200 (21580 m/s^2)
SIN FIT DURATION
.6735 (msec)
ALL CURVES HAVE SAME AREA


IMPACT PULSE 64
(Channel B)
PEAK 'G' LEVEL
3507 (34400 m/s^2)
TIME OF PULSE
1.024 (msec)
AREA OF PULSE
13.41 (m/s)
10
10
90
16
60
4
9
2
0
.341
.683
1.37
SEC E-03

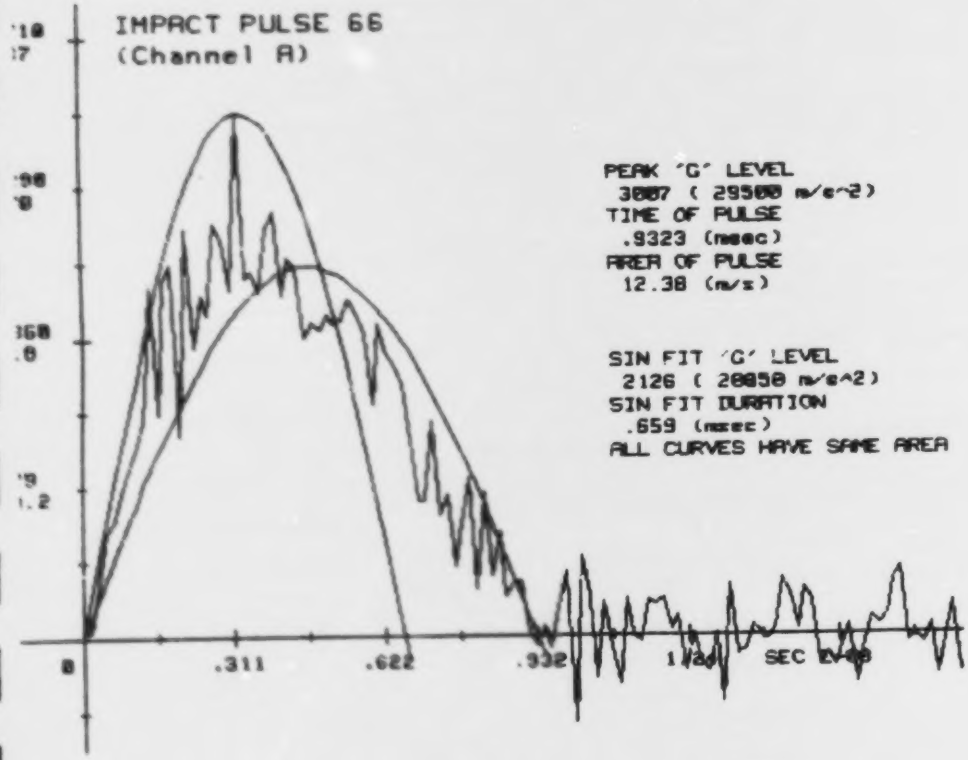

IMPACT PULSE 64
(Channel B)
PEAK 'G' LEVEL
3507 (34400 m/s^2)
TIME OF PULSE
1.024 (msec)
AREA OF PULSE
13.41 (m/s)
SIN FIT 'G' LEVEL
2096 (20560 m/s^2)
SIN FIT DURATION
.6121 (msec)
ALL CURVES HAVE SAME AREA
10
8
90
5
60
4
9
2
0
.341
.683
1.37
SEC E-03

```
          TEST DATE          SEPT 12 1984
          TEST NUMBER        66
-----------------------------------------------------------

BULB TYPE ( 4 -BULBS)                      GE-327
BULB #1 AGE (Hours)                         0
BULB #2 AGE (Hours)                         48
BULB #3 AGE (Hours)                         85
BULB #4 AGE (Hours)                         144
IMPACT MEDIUM                              WHITE PAD A
TEST VOLTAGE                               0
NUMBER OF SHOCK CORDS                       4
ACCELEROMETER (Channel A)                   827083
ACCELEROMETER (Channel B)                   827086
GAINS                                       1          1
10K FILTER- BULB 4 BROKE



RESISTANCE...
            BEFORE       AFTER        DELTA
-----------------------------------------------

BULB 1       78.387        78.346     -.040576
BULB 2       68.419        66.639     -1.7794
BULB 3       72.853        72.372     -.48128
BULB 4       81.213        99999       99918



             DAMAGE REPORT --> TEST 66
NUMBER  DAMAGE      (Peak G-  3262  )
----------------------------------------------------------------

BULB 1   None
BULB 2   None
BULB 3   None
BULB 4   1-frac.

COMMENTS...
BULB 1   -
BULB 2   -
BULB 3   -
BULB 4   NEAR RIGHT CONTACT POST- NO STRETCH EVIDENT
```



IMPACT PULSE 66
(Channel A)

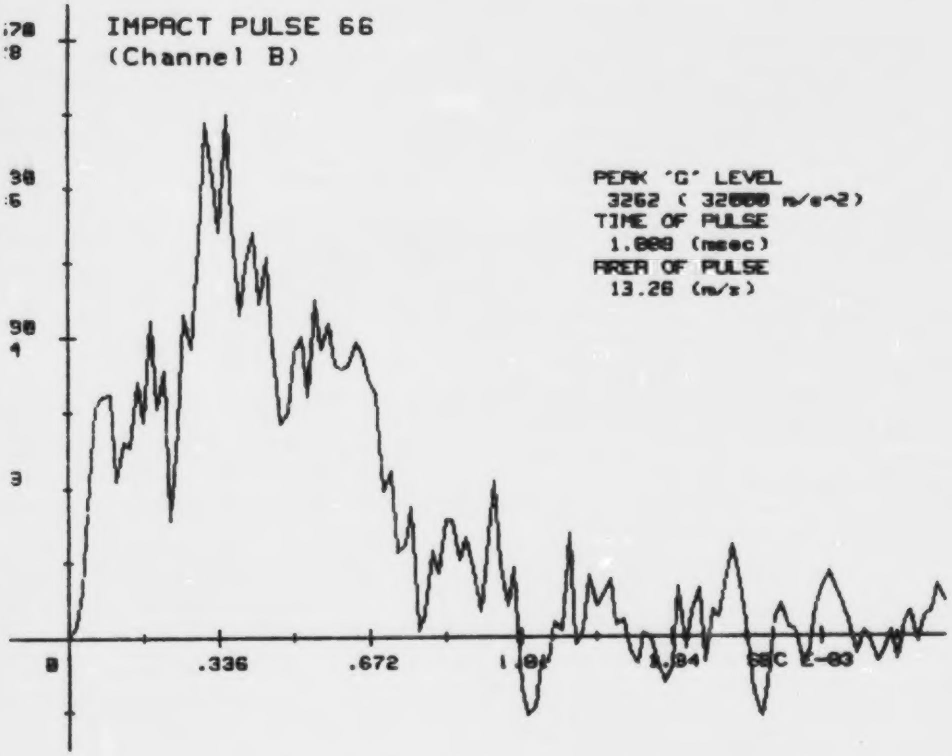
PEAK 'G' LEVEL
3007 (29500 m/s^2)
TIME OF PULSE
.9323 (msec)
AREA OF PULSE
12.38 (m/s)



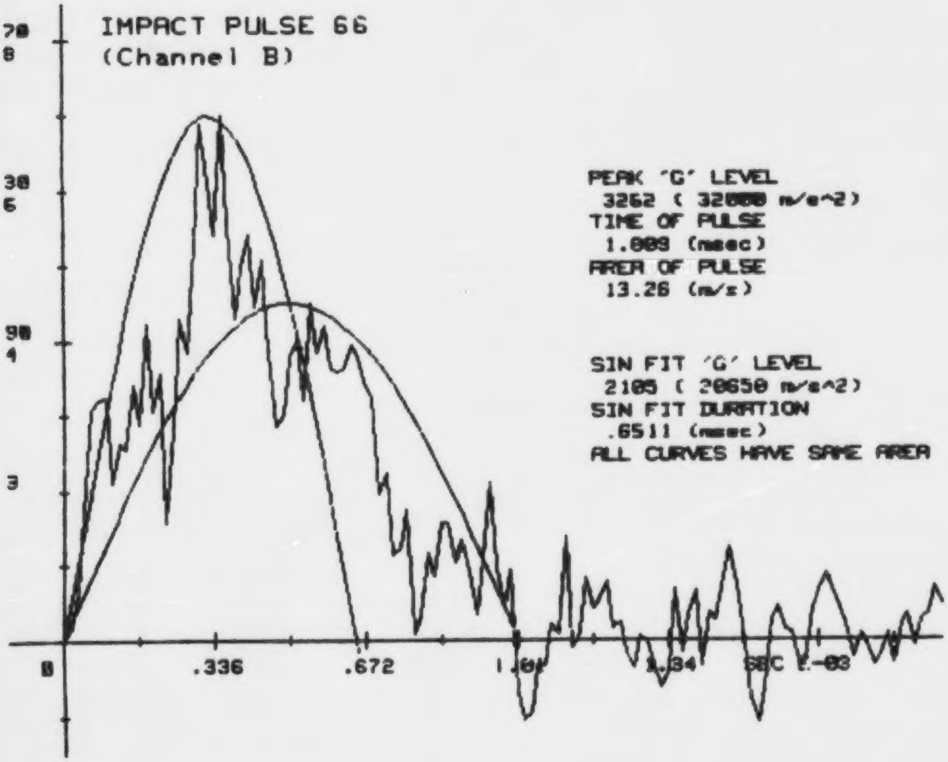
IMPACT PULSE 66
(Channel A)

PEAK 'G' LEVEL
3007 (29500 m/s^2)
TIME OF PULSE
.9323 (msec)
AREA OF PULSE
12.38 (m/s)

SIN FIT 'G' LEVEL
2126 (20850 m/s^2)
SIN FIT DURATION
.659 (msec)
ALL CURVES HAVE SAME AREA


IMPACT PULSE 66
(Channel B)

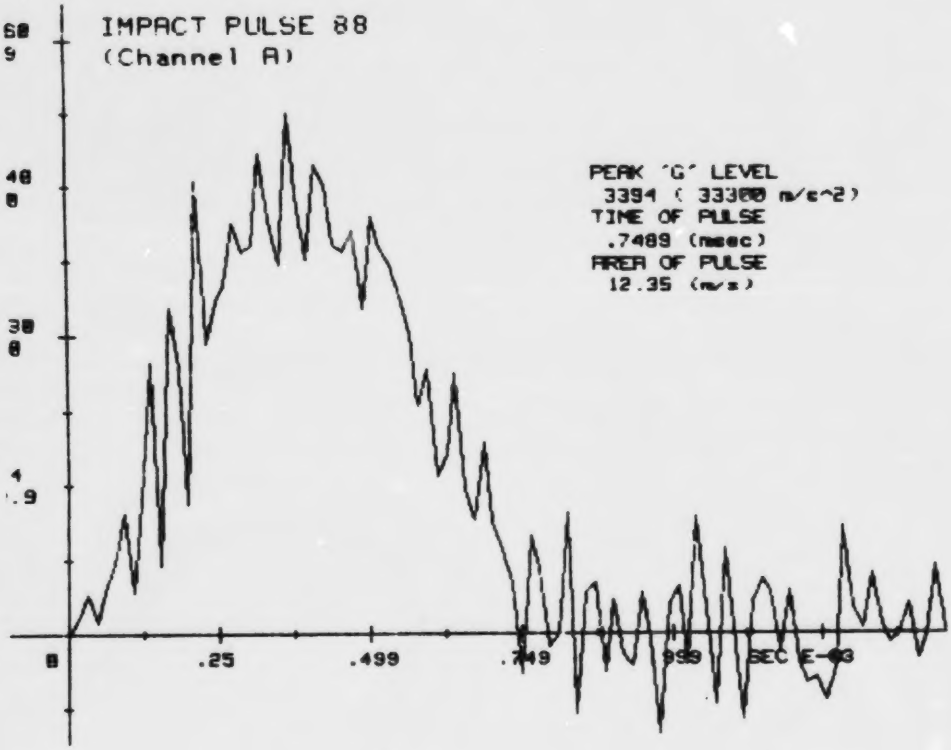
PEAK 'G' LEVEL
3262 (32000 m/s^2)
TIME OF PULSE
1.008 (msec)
AREA OF PULSE
13.26 (m/s)

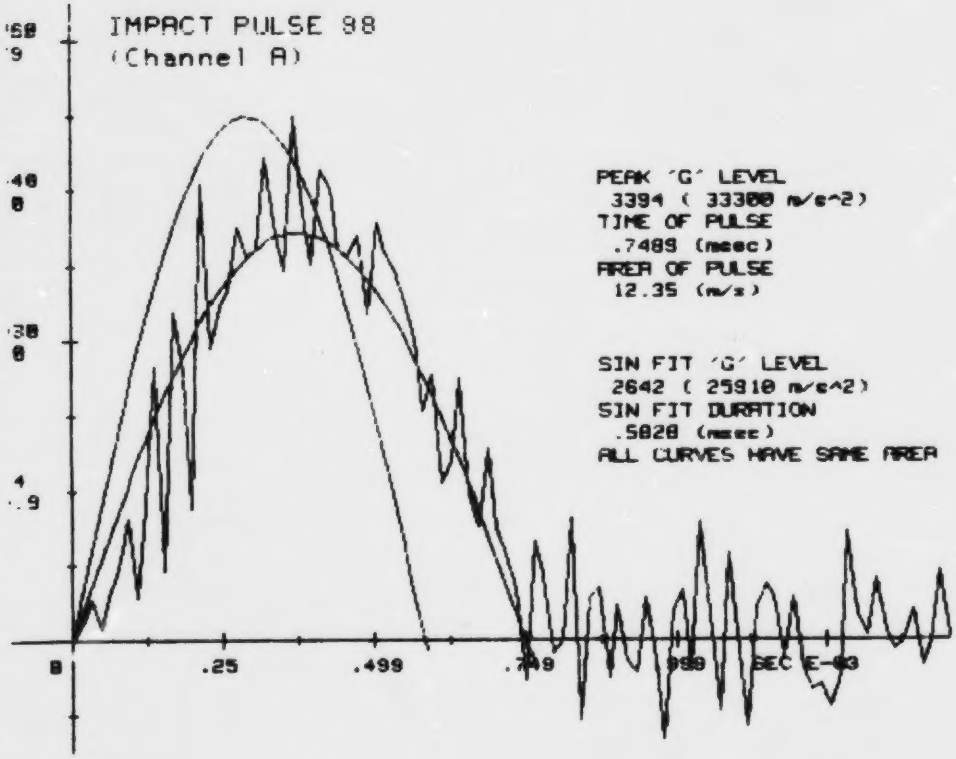

IMPACT PULSE 66
(Channel B)

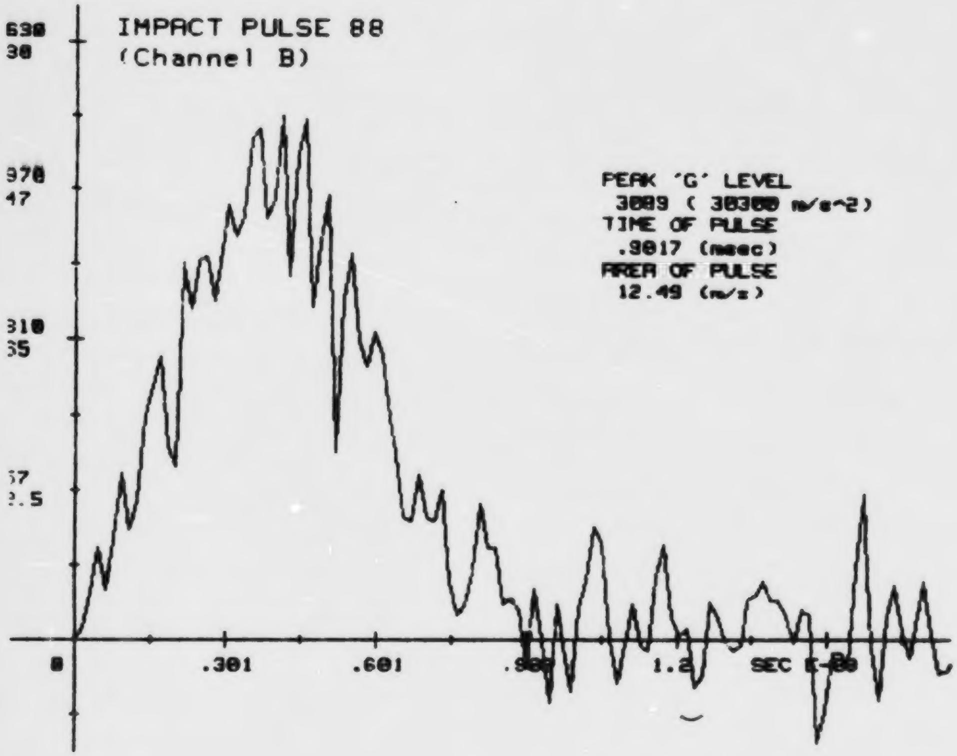
PEAK 'G' LEVEL
3262 (32000 m/s^2)
TIME OF PULSE
1.008 (msec)
AREA OF PULSE
13.26 (m/s)

SIN FIT 'G' LEVEL
2105 (20650 m/s^2)
SIN FIT DURATION
.6511 (msec)
ALL CURVES HAVE SAME AREA

```
                TEST DATE         SEPT 9 1984
                TEST NUMBER       88
          ----------------------------------------------------------

          BULB TYPE ( 4 -BULBS)                      GE-327
          BULB #1 AGE (Hours)                         0
          BULB #2 AGE (Hours)                         48
          BULB #3 AGE (Hours)                         85
          BULB #4 AGE (Hours)                         144
          IMPACT MEDIUM                              WHITE PAD B
          TEST VOLTAGE                               28
          NUMBER OF SHOCK CORDS                       2
          ACCELEROMETER (Channel A)                   827083
          ACCELEROMETER (Channel B)                   827086
          GAINS                                       1          1
          10K FILTER- BULB STAY ILLUMINATED



          RESISTANCE...
                         BEFORE       AFTER        DELTA
          ----------------------------------------------

          BULB 1          71.421       99999        99928
          BULB 2          64.801       99999        99934
          BULB 3          72.828       99999        99926
          BULB 4          69.167       42.556      -26.612



                          DAMAGE REPORT --> TEST 88
          NUMBER  DAMAGE       (Peak G-  3088.7  )
          ------------------------------------------------------------

          BULB 1   Gen. stretch Loc. stretch 2-frac.
          BULB 2   Gen. stretch Loc. stretch 1-frac.
          BULB 3   Gen. stretch Loc. stretch 1-frac.
          BULB 4   Gen. stretch Loc. stretch

          COMMENTS...
          BULB 1   MIDWAY BETWEEN BOTH CONTACTS AND SUPPORTS
          BULB 2   AT RIGHT CONTACT
          BULB 3   MIDWAY BETWEEN RIGHT CONTACT AND RIGHT SUPPORT
          BULB 4   SEVERE SNAKING
          TEST DATE          SEPT 9 1984
          TEST NUMBER        88
------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                    GE-327
BULB #1 AGE (Hours)                       0
BULB #2 AGE (Hours)                       48
BULB #3 AGE (Hours)                       96
BULB #4 AGE (Hours)                       144
IMPACT MEDIUM                            WHITE PAD B
TEST VOLTAGE                              28
NUMBER OF SHOCK CORDS                     2
ACCELEROMETER (Channel A)                 827083
ACCELEROMETER (Channel B)                 827086
GAINS                                     1          1
10K FILTER- BULB STAY ILLUMINATED

RESISTANCE...
          BEFORE       AFTER       DELTA
--------------------------------------------

BULB 1    71.421       99999       99928
BULB 2    64.801       99999       99934
BULB 3    72.828       99999       99926
BULB 4    69.167       42.556     -26.612


          DAMAGE REPORT --> TEST 88
NUMBER  DAMAGE      (Peak G-  3088.7  )
------------------------------------------------------------

BULB 1   Gen. stretch Loc. stretch 2-frac.
BULB 2   Gen. stretch Loc. stretch 1-frac.
BULB 3   Gen. stretch Loc. stretch 1-frac.
BULB 4   Gen. stretch Loc. stretch

COMMENTS...
BULB 1   MIDWAY BETWEEN BOTH CONTACTS AND SUPPORTS
BULB 2   AT RIGHT CONTACT
BULB 3   MIDWAY BETWEEN RIGHT CONTACT AND RIGHT SUPPORT
BULB 4   SEVERE SNAKING
```

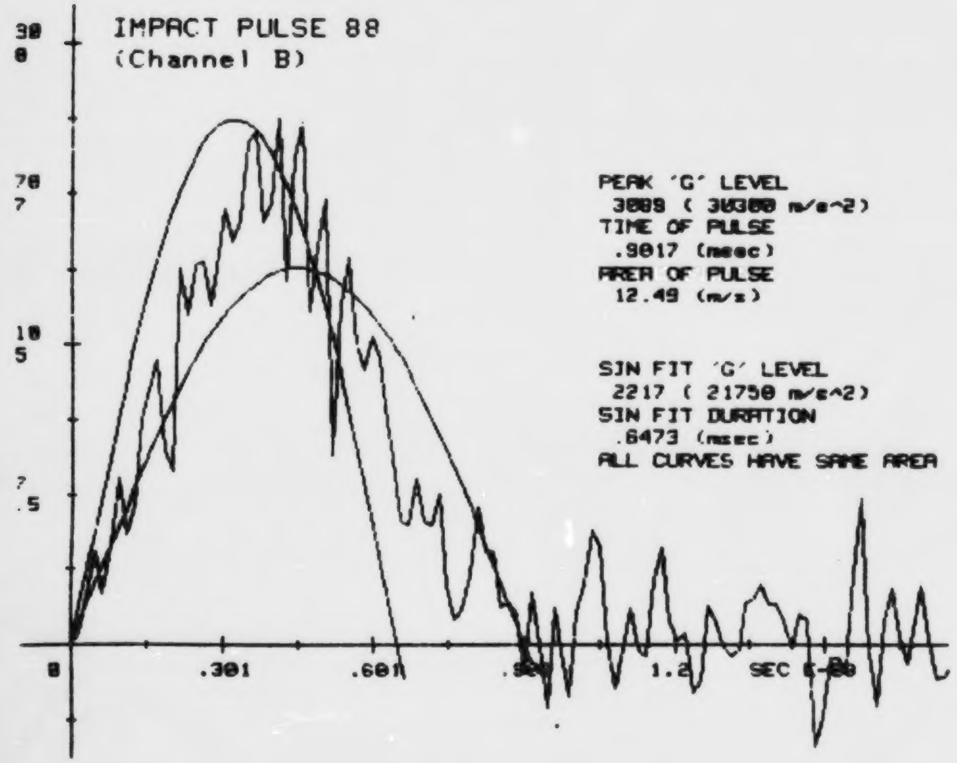

IMPACT PULSE 88
(Channel A)
50
9
40
0
30
0
4
.9
0
.25
.499
.749
.999
SEC E-03
PEAK 'G' LEVEL
3394 (33300 m/s^2)
TIME OF PULSE
.7489 (msec)
AREA OF PULSE
12.35 (m/s)


IMPACT PULSE 88
(Channel A)
50
9
40
0
30
0
4
.9
0
.25
.499
.749
.999
SEC E-03
PEAK 'G' LEVEL
3394 (33300 m/s^2)
TIME OF PULSE
.7489 (msec)
AREA OF PULSE
12.35 (m/s)
SIN FIT 'G' LEVEL
2642 (25910 m/s^2)
SIN FIT DURATION
.5828 (msec)
ALL CURVES HAVE SAME AREA



IMPACT PULSE 88
(Channel B)

PEAK 'G' LEVEL
3089 (30300 m/s^2)
TIME OF PULSE
.9017 (msec)
AREA OF PULSE
12.49 (m/s)

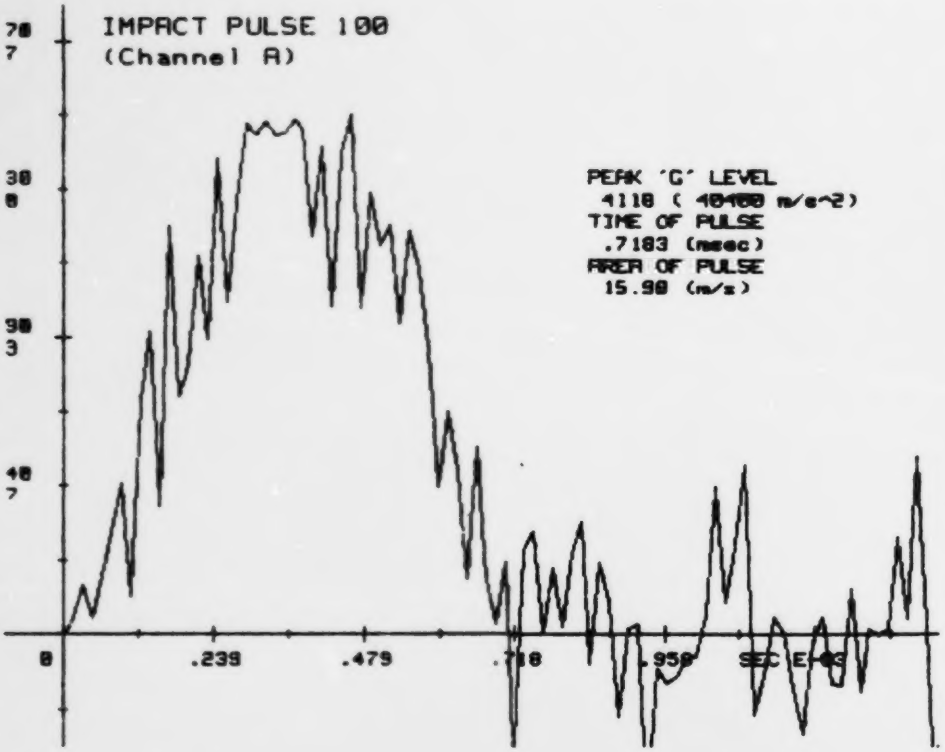


IMPACT PULSE 88
(Channel B)

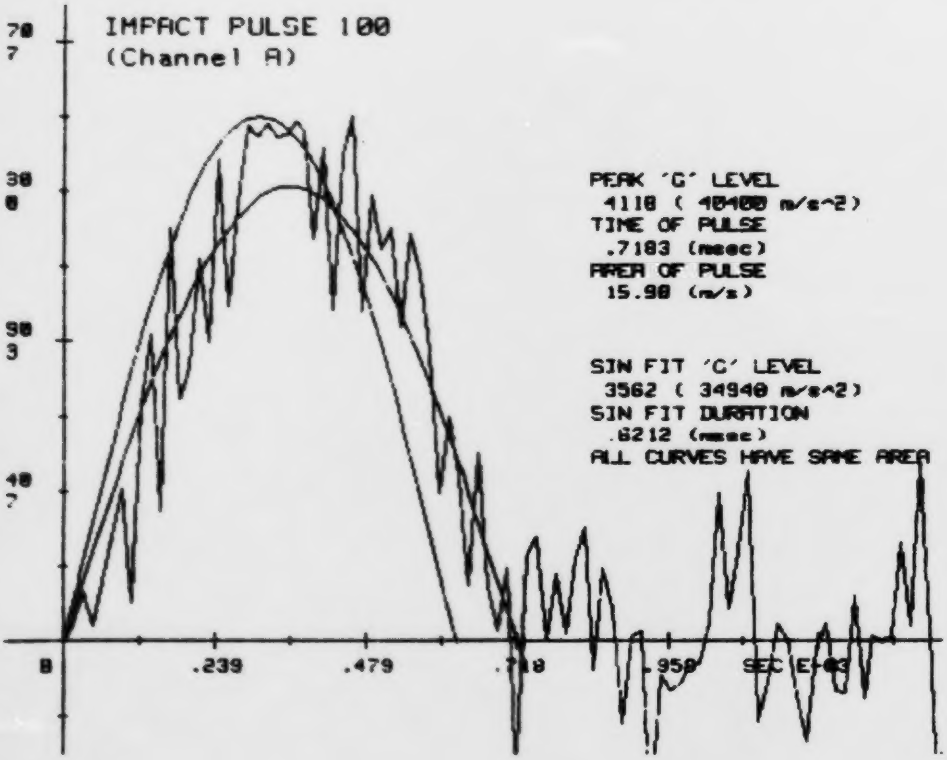
PEAK 'G' LEVEL
3089 (30300 m/s^2)
TIME OF PULSE
.9017 (msec)
AREA OF PULSE
12.49 (m/s)

SIN FIT 'G' LEVEL
2217 (21750 m/s^2)
SIN FIT DURATION
.6473 (msec)
ALL CURVES HAVE SAME AREA

```
              TEST DATE            OCT 11 1984
              TEST NUMBER          100
------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                         GE-327
BULB #1 AGE (Hours)                            0
BULB #2 AGE (Hours)                            48
BULB #3 AGE (Hours)                            85
BULB #4 AGE (Hours)                            144
IMPACT MEDIUM                                 WHITE PAD B
TEST VOLTAGE                                  28
NUMBER OF SHOCK CORDS                          8
ACCELEROMETER (Channel A)                      327083
ACCELEROMETER (Channel B)                      327086
GAINS                                          1         1
10 K FILTER  BULBS 3 AND 4 WENT OUT



RESISTANCE...
            BEFORE        AFTER        DELTA
---------------------------------------------------

BULB 1       77.258        29.361     -47.897
BULB 2       81.262        24.898     -56.364
BULB 3       75.723        99999       99923
BULB 4       69.096        99999       99930



               DAMAGE REPORT --> TEST 100
NUMBER  DAMAGE       (Peak G-  4006.1  )
------------------------------------------------------------------

BULB 1   Gen. stretch Loc. stretch
BULB 2   Gen. stretch Loc. stretch
BULB 3   Gen. stretch Loc. stretch 2-frac.
BULB 4   Gen. stretch Loc. stretch 2-frac.

COMMENTS...
BULB 1   ALMOST TOUCHING IN CENTER
BULB 2   STRETCHED ALL TO ONE SIDE
BULB 3   MIDWAY BETWEEN CONTACTS AND SUPPORTS
BULB 4   MIDWAY BETWEEN BOTH CONTACTS AND SUPPORTS  SEG. BROKE OFF
DLING
```

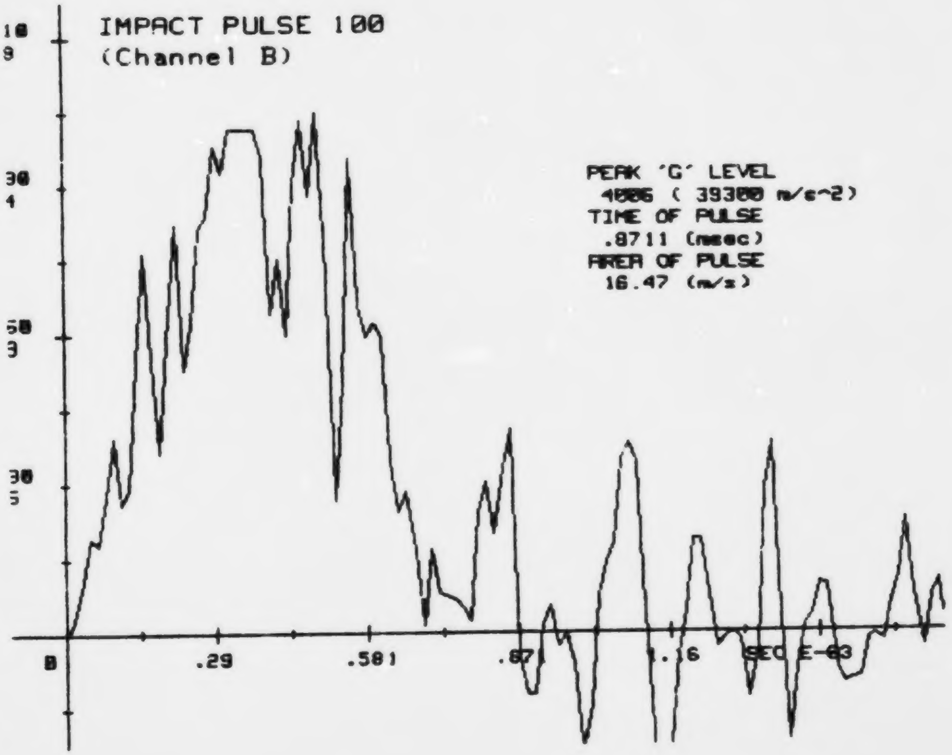


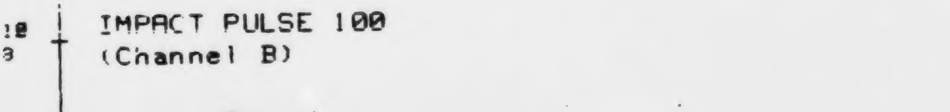
PEAK 'G' LEVEL
4118 (40400 m/s^2)
TIME OF PULSE
.7183 (msec)
AREA OF PULSE
15.90 (m/s)



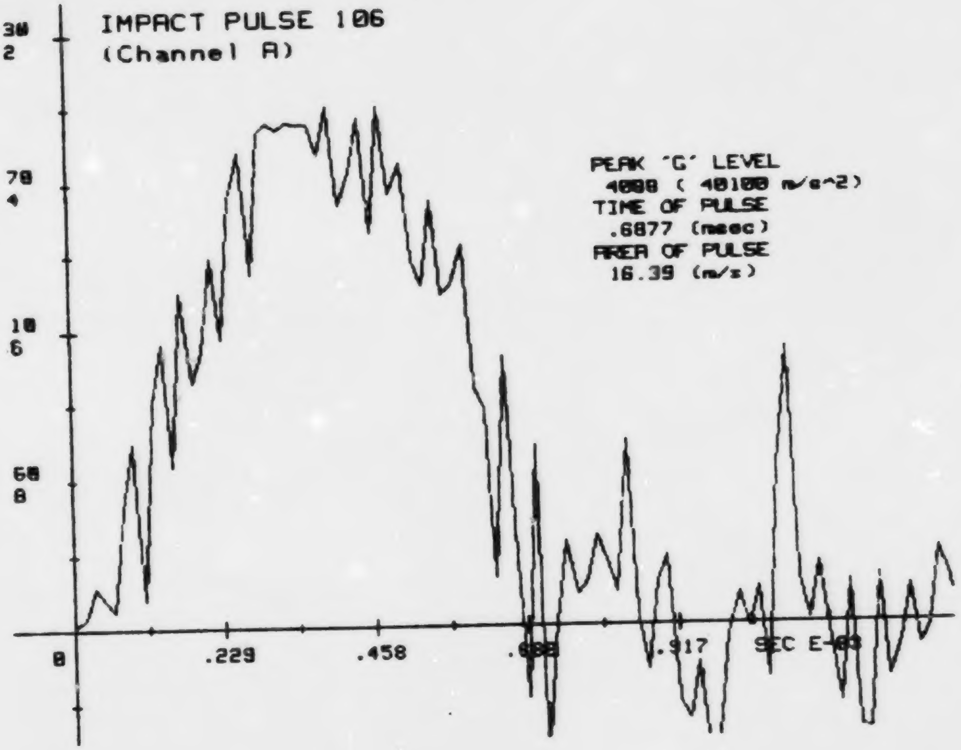
PEAK 'G' LEVEL
4118 (40400 m/s^2)
TIME OF PULSE
.7183 (msec)
AREA OF PULSE
15.90 (m/s)

SIN FIT 'G' LEVEL
3562 (34940 m/s^2)
SIN FIT DURATION
.6212 (msec)
ALL CURVES HAVE SAME AREA


IMPACT PULSE 100
(Channel B)
PEAK 'G' LEVEL
4006 (39300 m/s^2)
TIME OF PULSE
.8711 (msec)
AREA OF PULSE
16.47 (m/s)
10
9
30
4
50
3
30
5
0
.29
.581
.871
1.16
SEC E-03

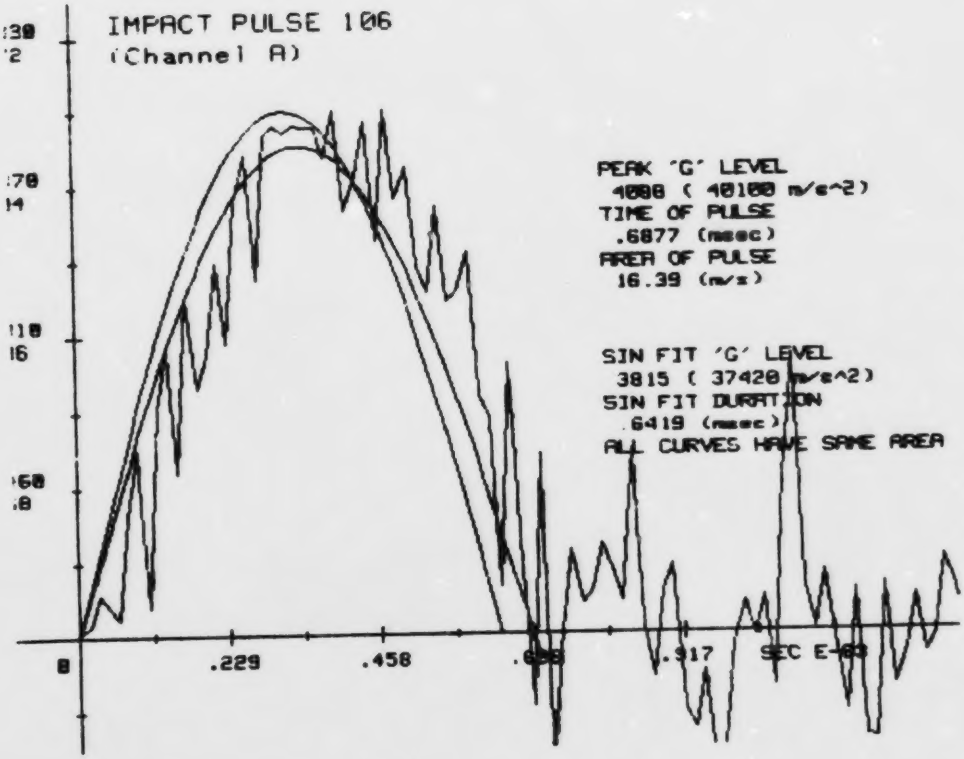

IMPACT PULSE 100
(Channel B)
PEAK 'G' LEVEL
4006 (39300 m/s^2)
TIME OF PULSE
.8711 (msec)
AREA OF PULSE
16.47 (m/s)
SIN FIT 'G' LEVEL
3027 (29700 m/s^2)
SIN FIT DURATION
.6583 (msec)
ALL CURVES HAVE SAME AREA
10
8
90
4
50
9
30
5
0
.29
.581
.871
1.16
SEC E-03

```
          TEST DATE          OCT 15 1984
          TEST NUMBER        106
    ---------------------------------------------------------

    BULB TYPE ( 4 -BULBS)                       GE-327
    BULB #1 AGE (Hours)                          0
    BULB #2 AGE (Hours)                          48
    BULB #3 AGE (Hours)                          85
    BULB #4 AGE (Hours)                          144
    IMPACT MEDIUM                               WHITE PAD B
    TEST VOLTAGE                                0
    NUMBER OF SHOCK CORDS                        10
    ACCELEROMETER (Channel A)                    827083
    ACCELEROMETER (Channel B)                    827086
    GAINS                                        1          1
    10K FILTER




    RESISTANCE...
                  BEFORE       AFTER        DELTA
    ------------------------------------------------

    BULB 1         72.34         75.606     3.2656
    BULB 2         70.263        99999      99929
    BULB 3         79.817        99999      99919
    BULB 4         73.709        70.923    -2.7862



                  DAMAGE REPORT --> TEST 106
    NUMBER  DAMAGE      (Peak G-  4016.3  )
    ------------------------------------------------------------

    BULB 1   None
    BULB 2   1-frac.
    BULB 3   Loc. stretch 1-frac.
    BULB 4   None

    COMMENTS...
    BULB 1   POSSIBLE SLIGHT GEN. STRETCH- DISTORTIION OF COIL NEAR RI
    BULB 2   NEAR LEFT CONTACT POST  POSSIBLE GEN STRETCH
    BULB 3   NEAR RIGHT SUPPORT- LOC STRETCH BETWEEN SUPPORTS
    BULB 4   POSSIBLE GENERAL STRETCH
```



IMPACT PULSE 106
(Channel A)

PEAK 'G' LEVEL
4088 (40100 m/s^2)
TIME OF PULSE
.6877 (msec)
AREA OF PULSE
16.39 (m/s)

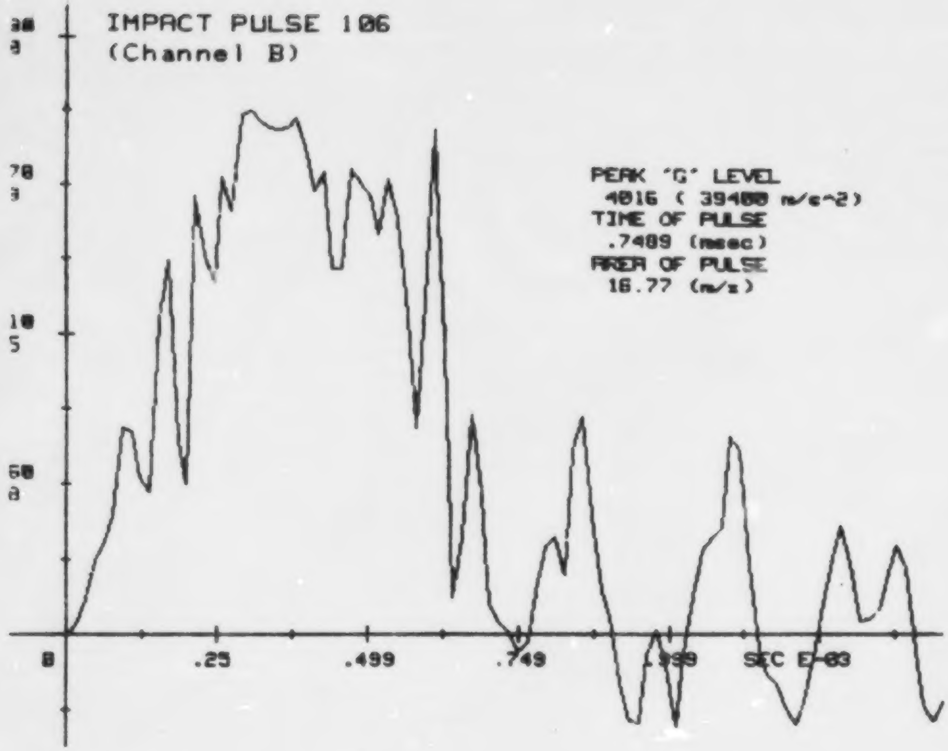


IMPACT PULSE 106
(Channel A)

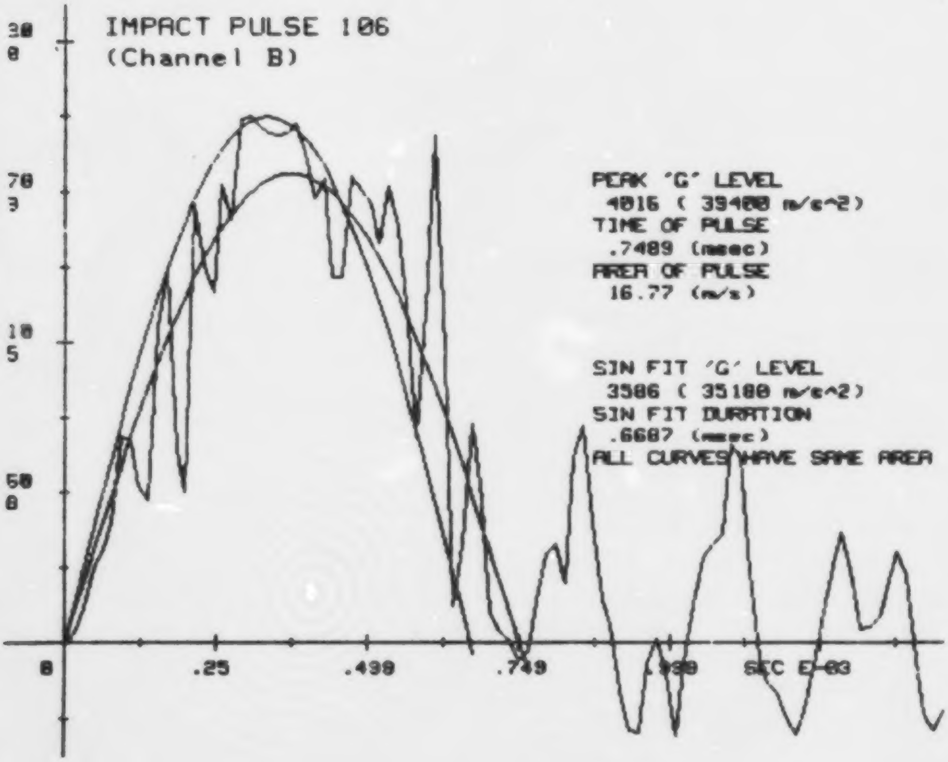
PEAK 'G' LEVEL
4088 (40100 m/s^2)
TIME OF PULSE
.6877 (msec)
AREA OF PULSE
16.39 (m/s)

SIN FIT 'G' LEVEL
3815 (37420 m/s^2)
SIN FIT DURATION
.6419 (msec)
ALL CURVES HAVE SAME AREA

A -42


IMPACT PULSE 106
(Channel B)

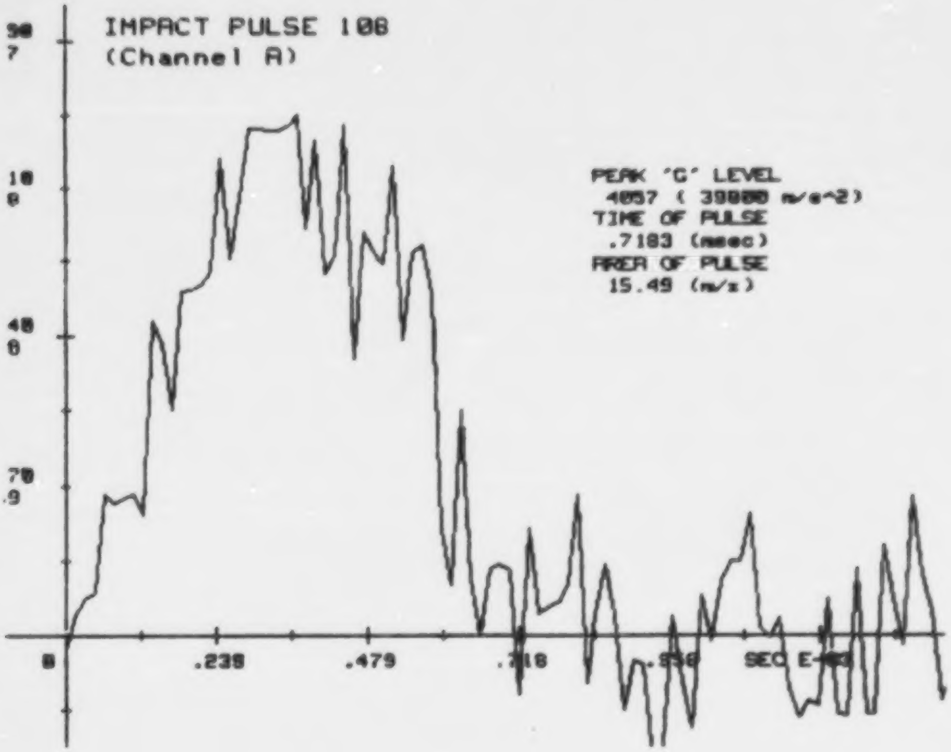
PEAK 'G' LEVEL
 4016 (39400 m/s^2)
TIME OF PULSE
 .7489 (msec)
AREA OF PULSE
 16.77 (m/s)

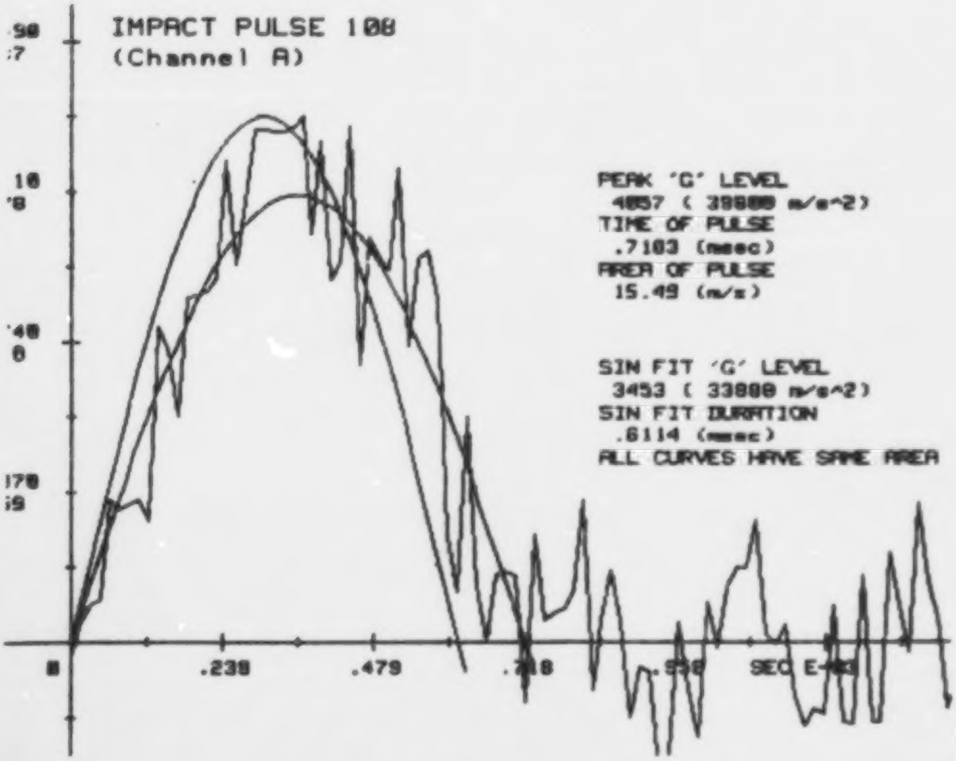

IMPACT PULSE 106
(Channel B)

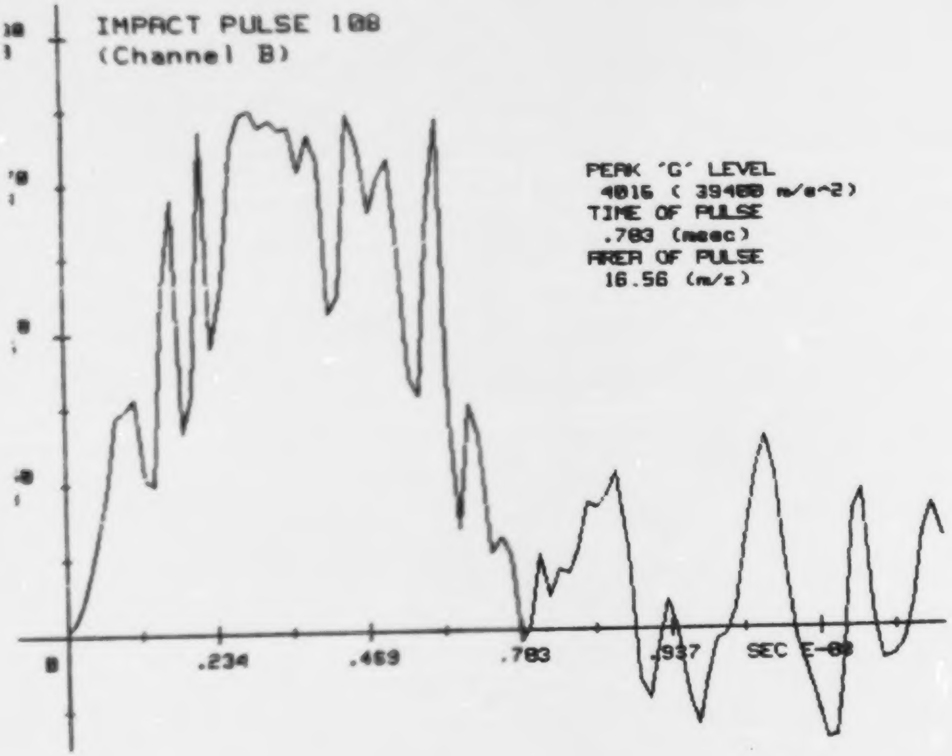
PEAK 'G' LEVEL
 4016 (39400 m/s^2)
TIME OF PULSE
 .7489 (msec)
AREA OF PULSE
 16.77 (m/s)

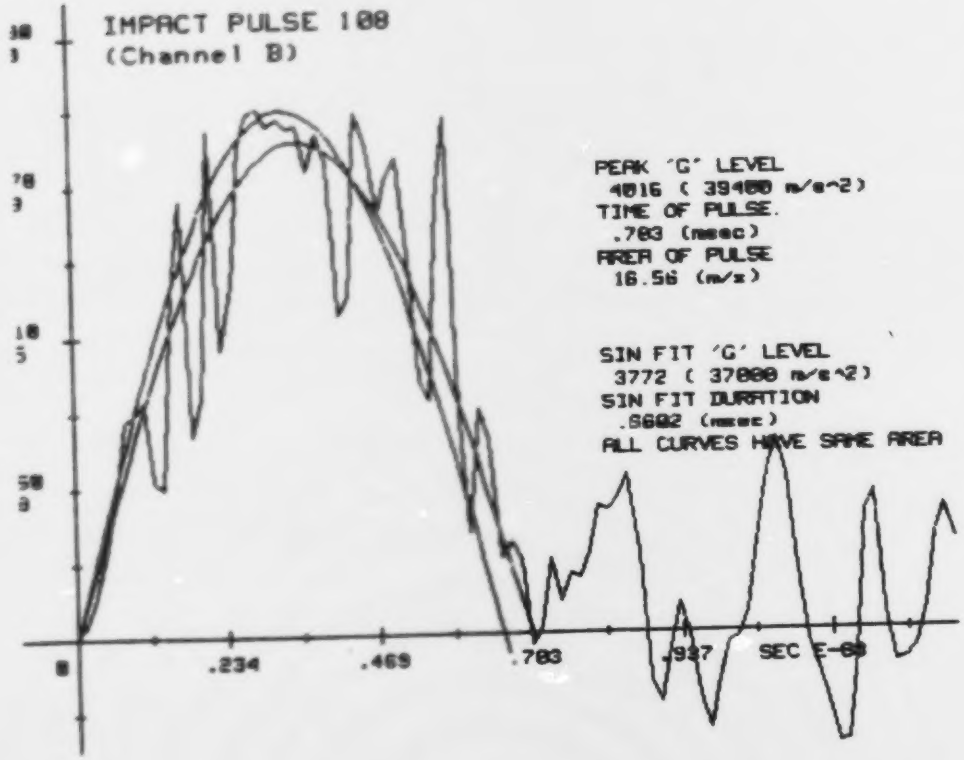
SIN FIT 'G' LEVEL
 3586 (35180 m/s^2)
SIN FIT DURATION
 .6687 (msec)
ALL CURVES HAVE SAME AREA

```
          TEST DATE          OCT 15 1984
          TEST NUMBER        108
------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                    GE-327
BULB #1 AGE (Hours)                       210
BULB #2 AGE (Hours)                       210
BULB #3 AGE (Hours)                       250
BULB #4 AGE (Hours)                       250
IMPACT MEDIUM                            WHITE PAD B
TEST VOLTAGE                             0
NUMBER OF SHOCK CORDS                     10
ACCELEROMETER (Channel A)                 827083
ACCELEROMETER (Channel B)                 827086
GAINS                                     1          1
10 K FILTER



RESISTANCE...
            BEFORE       AFTER        DELTA
-------------------------------------------------

BULB 1       68.716        99999      99930
BULB 2       75.809        78.421     2.6122
BULB 3       77.885        99999      99921
BULB 4       99999         99999      0



             DAMAGE REPORT --> TEST 108
NUMBER  DAMAGE      (Peak G-  4016.3  )
-----------------------------------------------------------------

BULB 1   several frac.
BULB 2   Gen. stretch
BULB 3   1-frac.
BULB 4   1-frac.

COMMENTS...
BULB 1   NO STRETCH
BULB 2   SIMILAR TO LOW IMPACT HOT TESTS***
BULB 3   NEAR RIGHT SUPPORT
BULB 4   NEAR RIGHT CONTACT
```

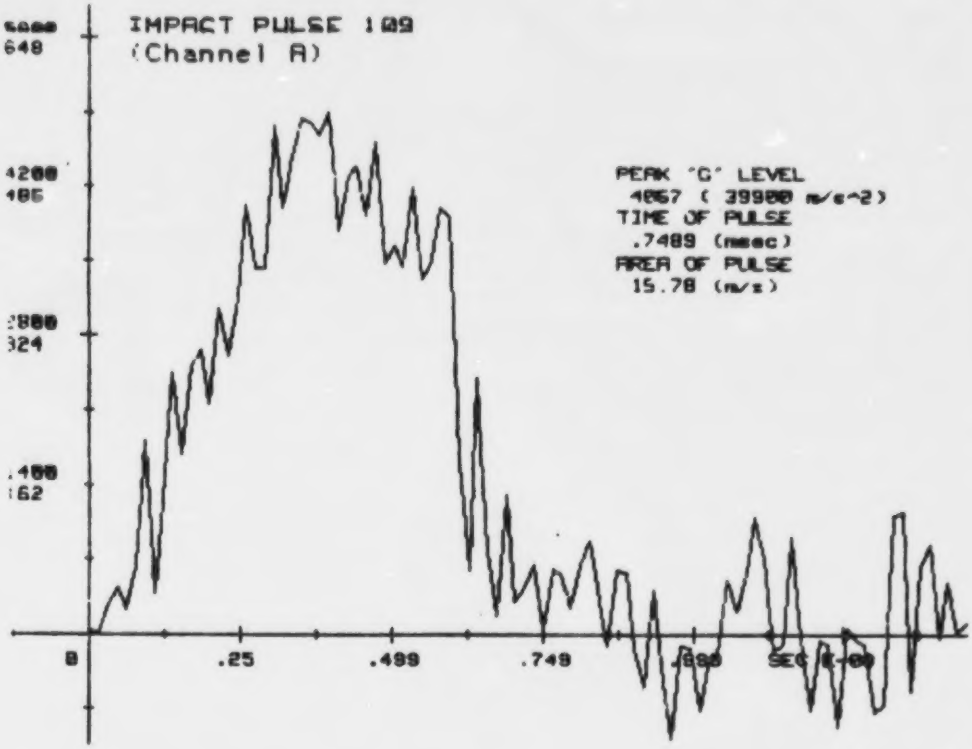

90
7
IMPACT PULSE 108
(Channel A)
10
0
40
0
70
.9
PEAK 'G' LEVEL
4057 (39800 m/s^2)
TIME OF PULSE
.7103 (msec)
AREA OF PULSE
15.49 (m/s)
0
.238
.479
.718
.958
SEC E-03


90
7
IMPACT PULSE 108
(Channel A)
10
0
40
0
70
.9
PEAK 'G' LEVEL
4057 (39800 m/s^2)
TIME OF PULSE
.7103 (msec)
AREA OF PULSE
15.49 (m/s)
SIN FIT 'G' LEVEL
3453 (33800 m/s^2)
SIN FIT DURATION
.6114 (msec)
ALL CURVES HAVE SAME AREA
0
.238
.479
.718
.958
SEC E-03

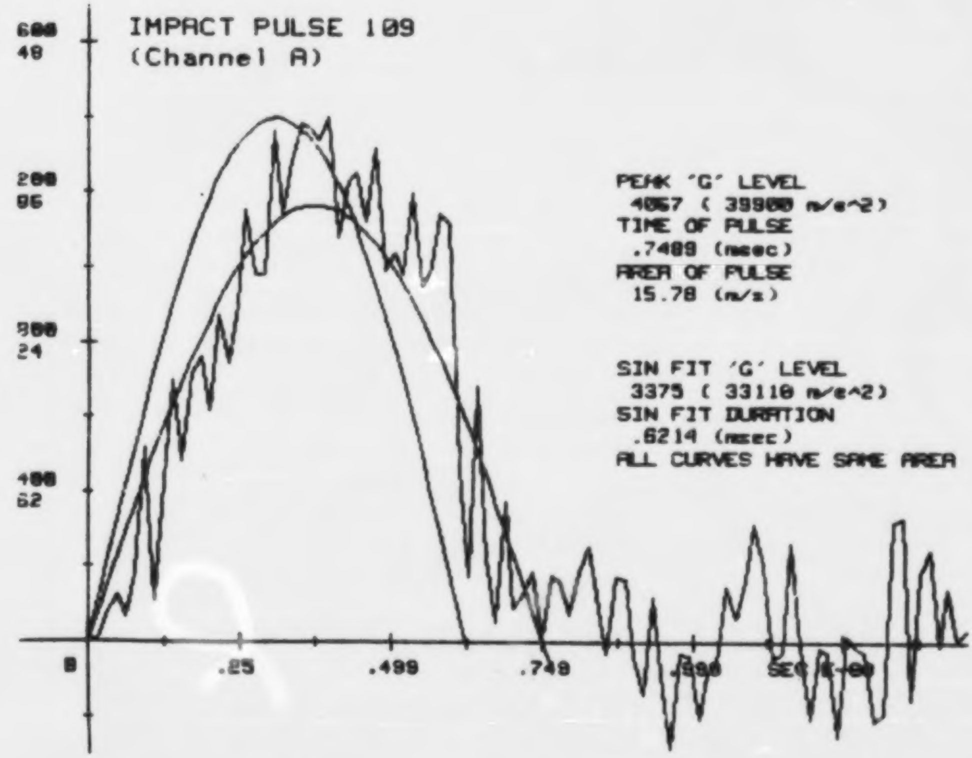

IMPACT PULSE 100
(Channel B)
PEAK 'G' LEVEL
4016 (39400 m/s^2)
TIME OF PULSE
.703 (msec)
AREA OF PULSE
16.56 (m/s)
0
.234
.469
.703
.937
SEC E-03


IMPACT PULSE 100
(Channel B)
30
70
10
50
PEAK 'G' LEVEL
4016 (39400 m/s^2)
TIME OF PULSE.
.703 (msec)
AREA OF PULSE
16.56 (m/s)
SIN FIT 'G' LEVEL
3772 (37000 m/s^2)
SIN FIT DURATION
.6602 (msec)
ALL CURVES HAVE SAME AREA
0
.234
.469
.703
.937
SEC E-03

```
          TEST DATE         OCT 15 1984
          TEST NUMBER       109
-------------------------------------------------------------

BULB TYPE ( 4 -BULBS)                     GE-327
BULB #1 AGE (Hours)                        210
BULB #2 AGE (Hours)                        210
BULB #3 AGE (Hours)                        250
BULB #4 AGE (Hours)                        250
IMPACT MEDIUM                             WHITE PAD B
TEST VOLTAGE                              0
NUMBER OF SHOCK CORDS                      10
ACCELEROMETER (Channel A)                  827083
ACCELEROMETER (Channel B)                  827086
GAINS                                      1         1
10K FILTER  ALL BULBS BROKE  #4 WAS BROKEN PRIOR TO IMPACT




RESISTANCE...
            BEFORE       AFTER        DELTA
------------------------------------------------

BULB 1       70.708        99999       99928
BULB 2       75.688        99999       99923
BULB 3       69.351        99999       99930
BULB 4       99999         99999       0



             DAMAGE REPORT --> TEST 109
NUMBER  DAMAGE      (Peak G-  3945   )
-----------------------------------------------------------------

BULB 1   several frac.
BULB 2   2-frac.
BULB 3   several frac.
BULB 4   None

COMMENTS...
BULB 1
BULB 2   MIDWAY BETWEEN BOTH SIDES
BULB 3
BULB 4   BROKEN BEFORE TEST
```

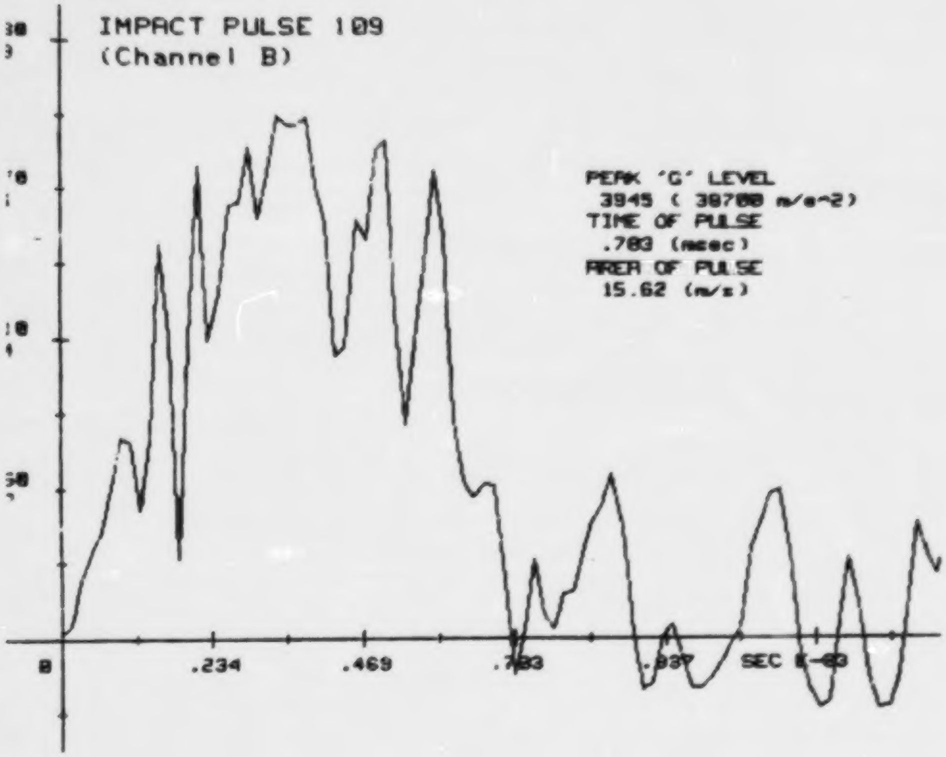


PEAK 'G' LEVEL
4067 (39900 m/s^2)
TIME OF PULSE
.7489 (msec)
AREA OF PULSE
15.70 (m/s)



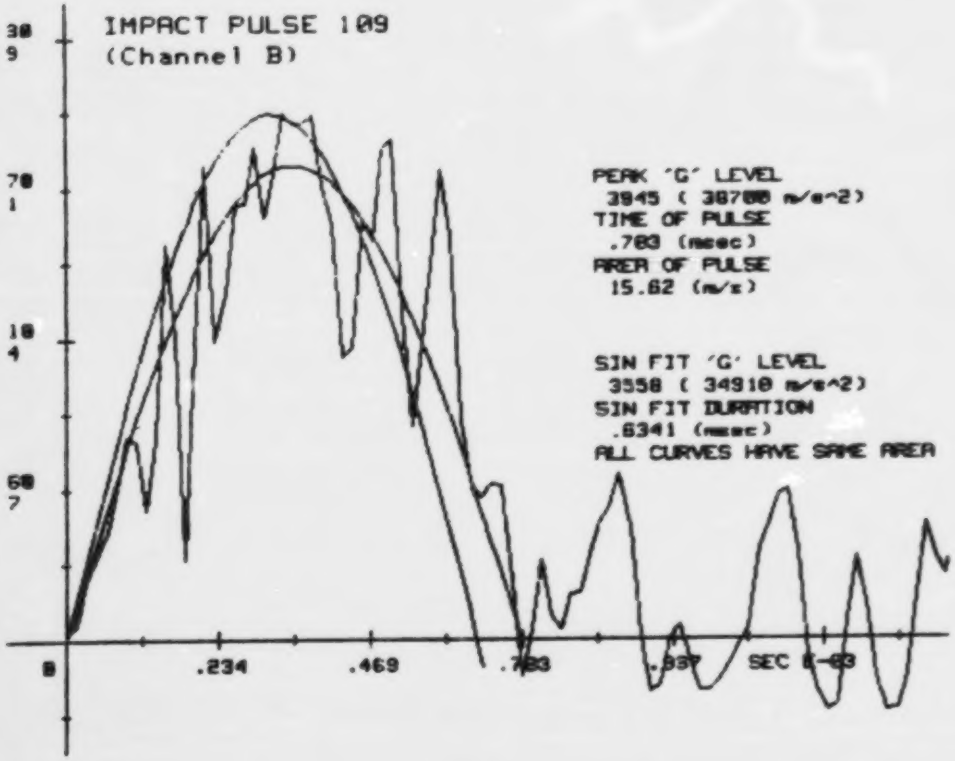
PEAK 'G' LEVEL
4067 (39900 m/s^2)
TIME OF PULSE
.7489 (msec)
AREA OF PULSE
15.70 (m/s)

SIN FIT 'G' LEVEL
3375 (33110 m/s^2)
SIN FIT DURATION
.6214 (msec)
ALL CURVES HAVE SAME AREA



IMPACT PULSE 109
(Channel B)

PEAK 'G' LEVEL
3945 (38700 m/s^2)
TIME OF PULSE
.703 (msec)
AREA OF PULSE
15.62 (m/s)

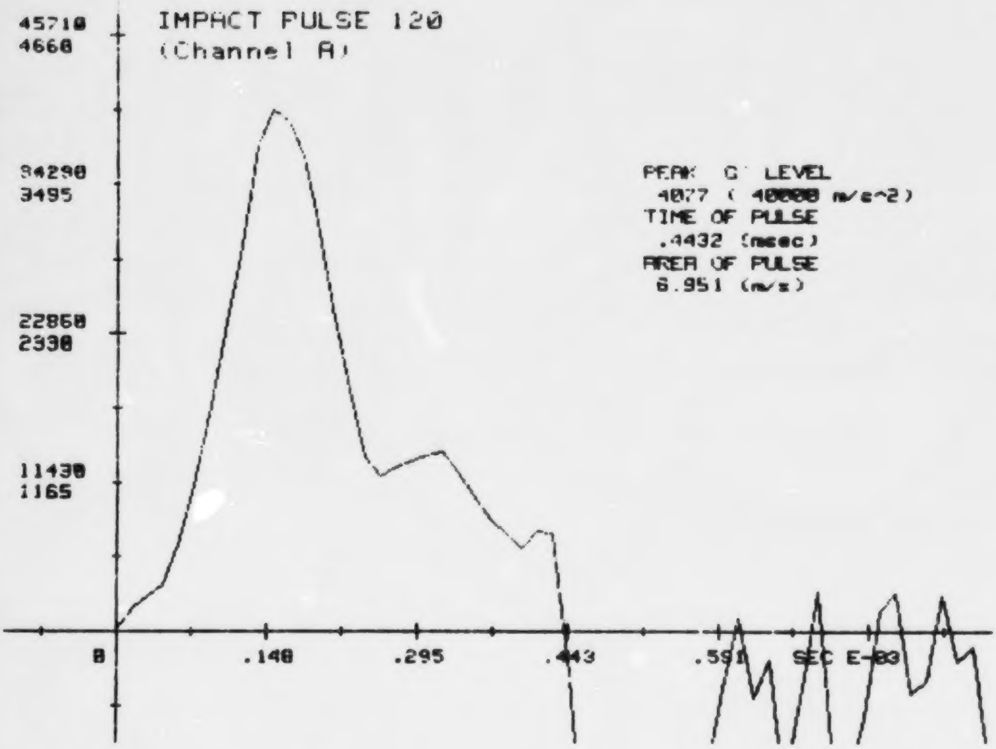


IMPACT PULSE 109
(Channel B)

PEAK 'G' LEVEL
3945 (38700 m/s^2)
TIME OF PULSE
.703 (msec)
AREA OF PULSE
15.62 (m/s)

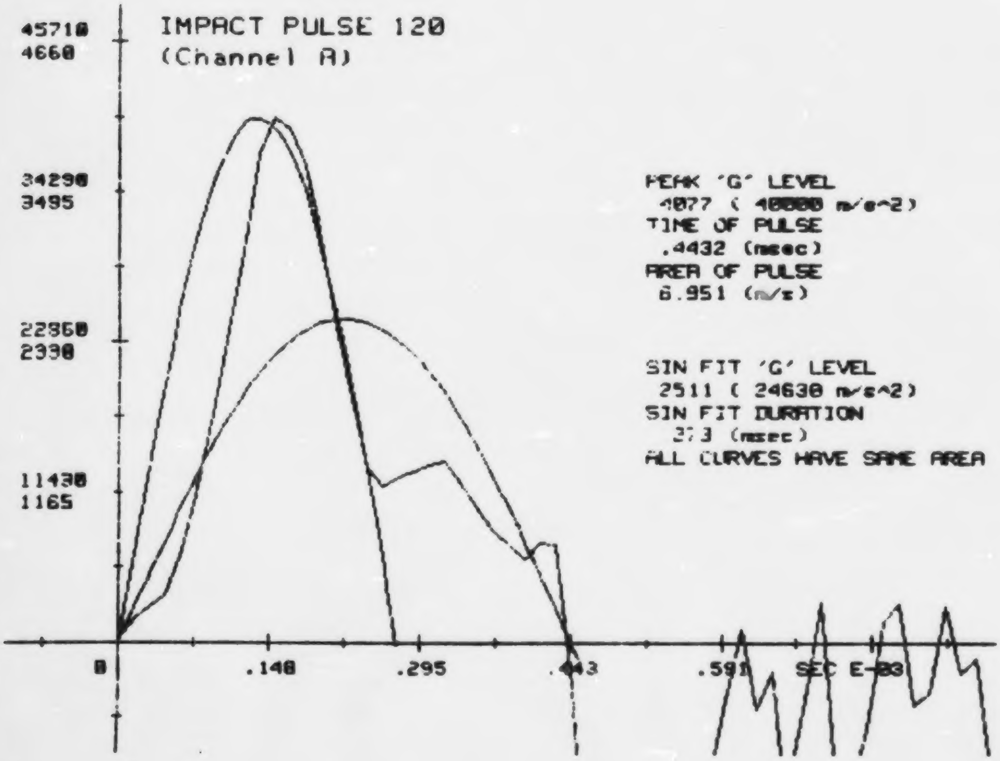
SIN FIT 'G' LEVEL
3558 (34910 m/s^2)
SIN FIT DURATION
.6341 (msec)
ALL CURVES HAVE SAME AREA

```
            TEST DATE        26 MARCH 1985
            TEST NUMBER      120
-----------------------------------------------------------

BULB TYPE ( 1 -BULBS)                    GE-327
BULB #1 AGE (Hours)                       210
BULB #2 AGE (Hours)                       0
BULB #3 AGE (Hours)                       0
BULB #4 AGE (Hours)                       0
IMPACT MEDIUM                            HAMMER
TEST VOLTAGE                             28
NUMBER OF SHOCK CORDS                     0
ACCELEROMETER (Channel A)                 827083
ACCELEROMETER (Channel B)                 827086
GAINS                                     1          1
WENT CONSIDERABLY BRIGHTER AFTER IMPACT



RESISTANCE...
            BEFORE       AFTER        DELTA
-----------------------------------------------

BULB 1       0            0            0
BULB 2       0            0            0
BULB 3       0            0            0
BULB 4       0            0            0
```



IMPACT PULSE 120
(Channel A)

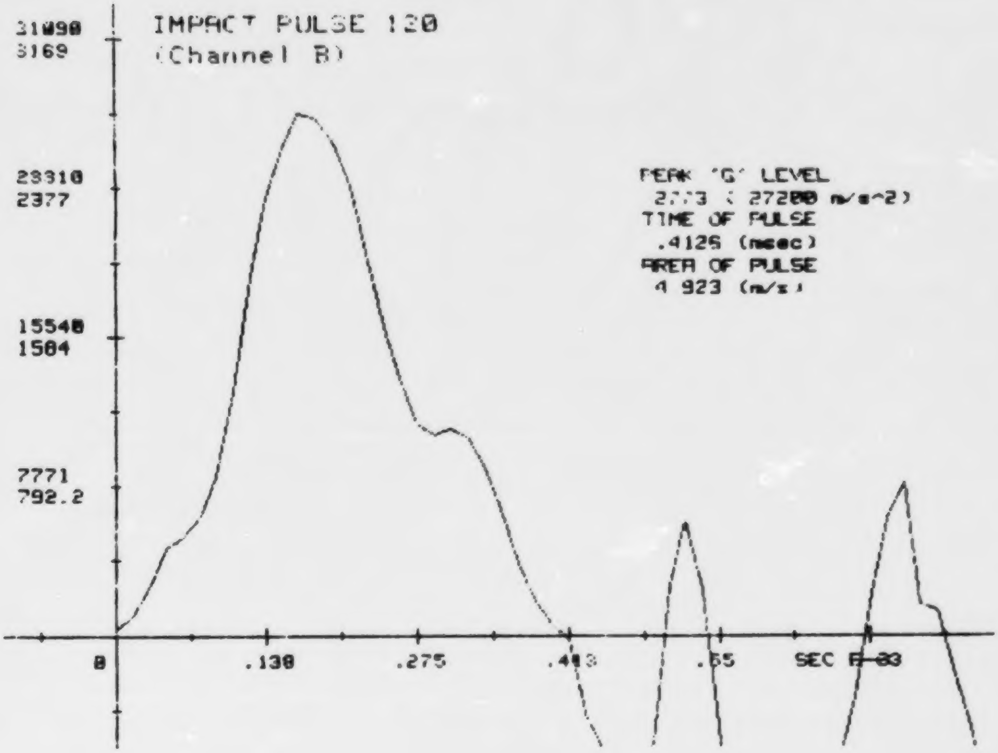
PEAK 'G' LEVEL
4077 (40000 m/s^2)
TIME OF PULSE
.4432 (msec)
AREA OF PULSE
6.951 (m/s)



IMPACT PULSE 120
(Channel A)

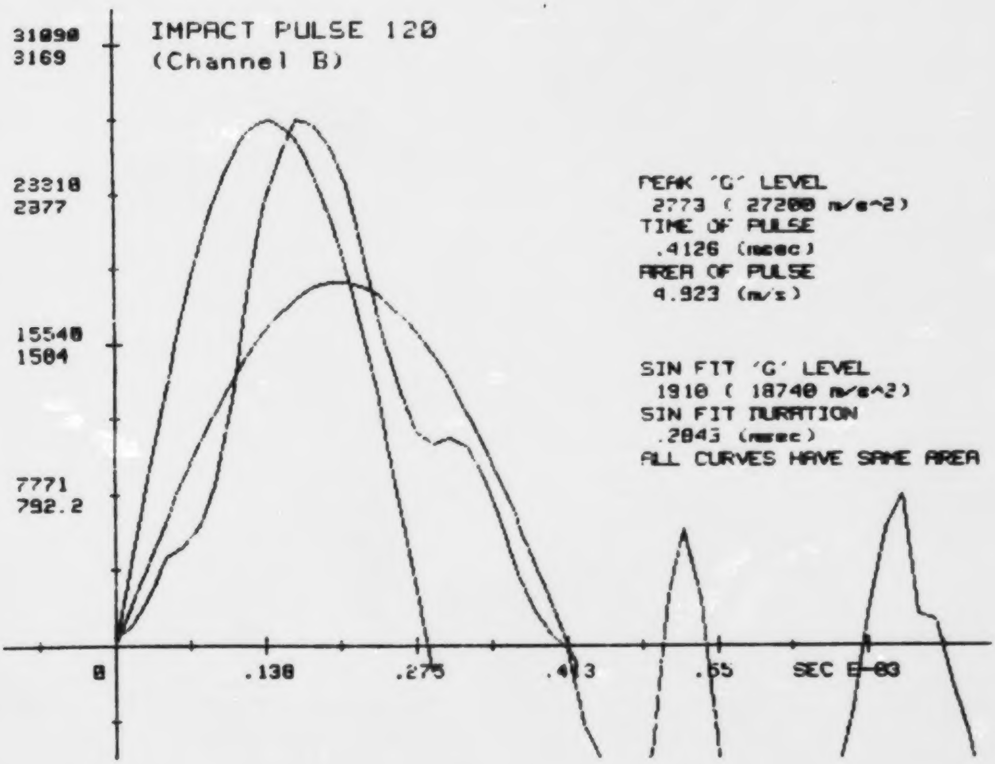
PEAK 'G' LEVEL
4077 (40000 m/s^2)
TIME OF PULSE
.4432 (msec)
AREA OF PULSE
6.951 (m/s)

SIN FIT 'G' LEVEL
2511 (24630 m/s^2)
SIN FIT DURATION
373 (msec)
ALL CURVES HAVE SAME AREA



IMPACT PULSE 120
(Channel B)

PEAK 'G' LEVEL
2773 (27200 m/s^2)
TIME OF PULSE
.4126 (msec)
AREA OF PULSE
4.923 (m/s)

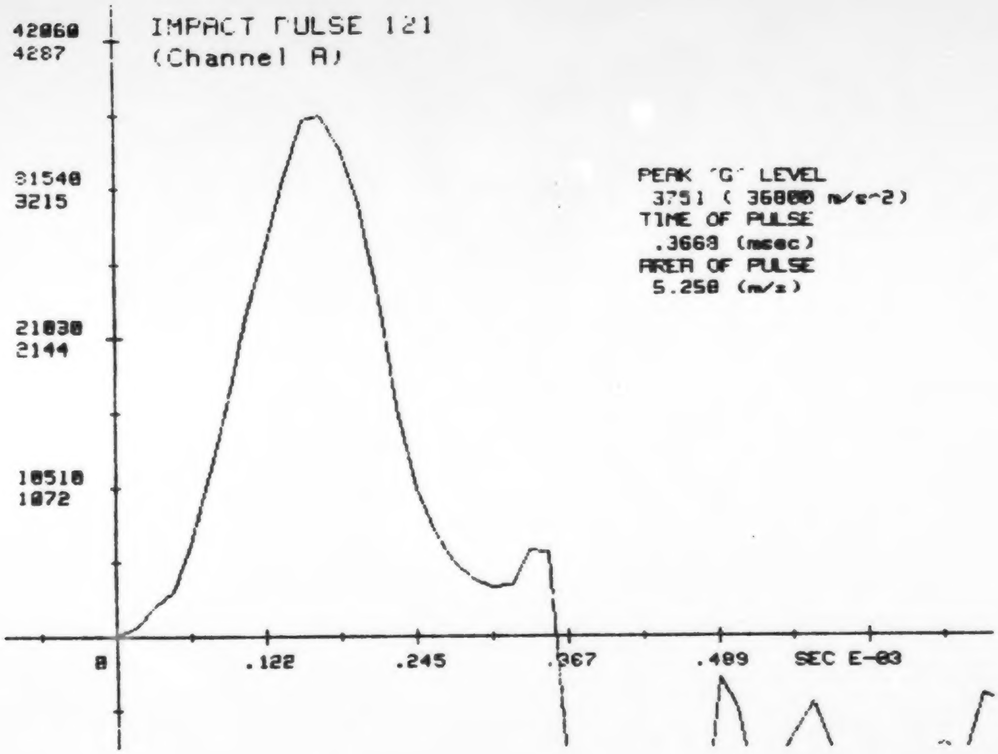


IMPACT PULSE 120
(Channel B)

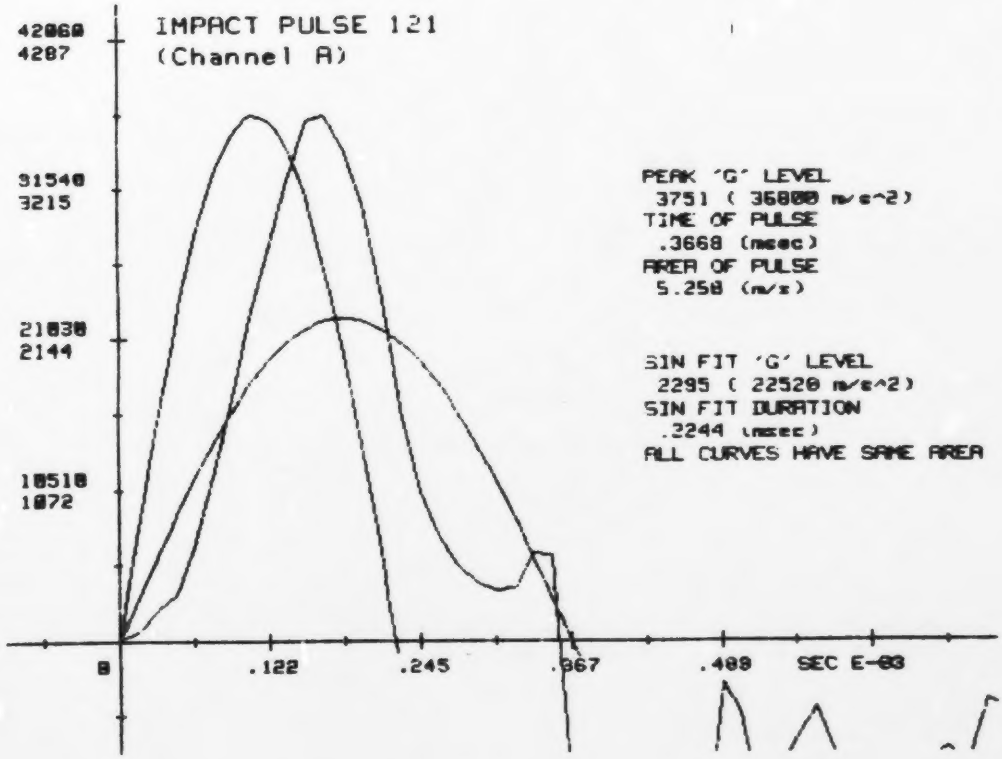
PEAK 'G' LEVEL
2773 (27200 m/s^2)
TIME OF PULSE
.4126 (msec)
AREA OF PULSE
4.923 (m/s)

SIN FIT 'G' LEVEL
1910 (18740 m/s^2)
SIN FIT DURATION
.2843 (msec)
ALL CURVES HAVE SAME AREA

```
          TEST DATE          MARCH 26 1985
          TEST NUMBER        121
------------------------------------------------------------

BULB TYPE ( 1 -BULBS)                         GE-327
BULB #1 AGE (Hours)                            210
BULB #2 AGE (Hours)                            0
BULB #3 AGE (Hours)                            0
BULB #4 AGE (Hours)                            0
IMPACT MEDIUM                                 HAMMER
TEST VOLTAGE                                  0
NUMBER OF SHOCK CORDS                          0
ACCELEROMETER (Channel A)                     827083
ACCELEROMETER (Channel B)                     827086
GAINS                                          1          1
FRACTURED IN 2 LOCATIONS  NO STRETCH



RESISTANCE...
           BEFORE       AFTER        DELTA
-------------------------------------------------

BULB 1       0            0            0
BULB 2       0            0            0
BULB 3       0            0            0
BULB 4       0            0            0
```

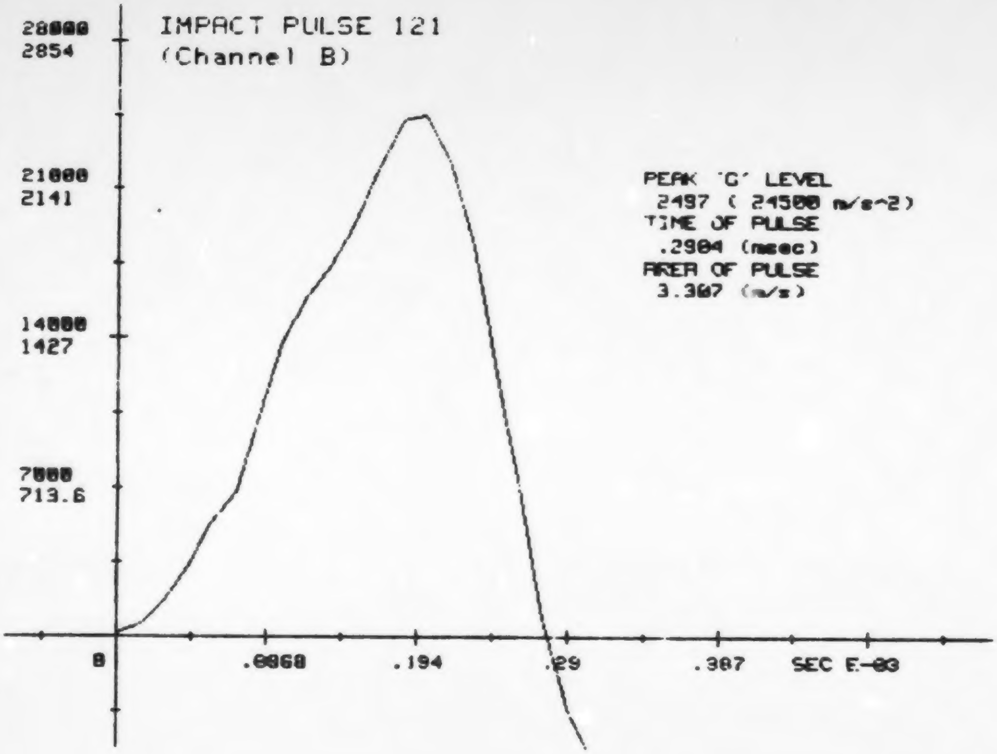

IMPACT PULSE 121
(Channel A)

PEAK 'G' LEVEL
3751 (36800 m/s^2)
TIME OF PULSE
.3668 (msec)
AREA OF PULSE
5.258 (m/s)


IMPACT PULSE 121
(Channel A)

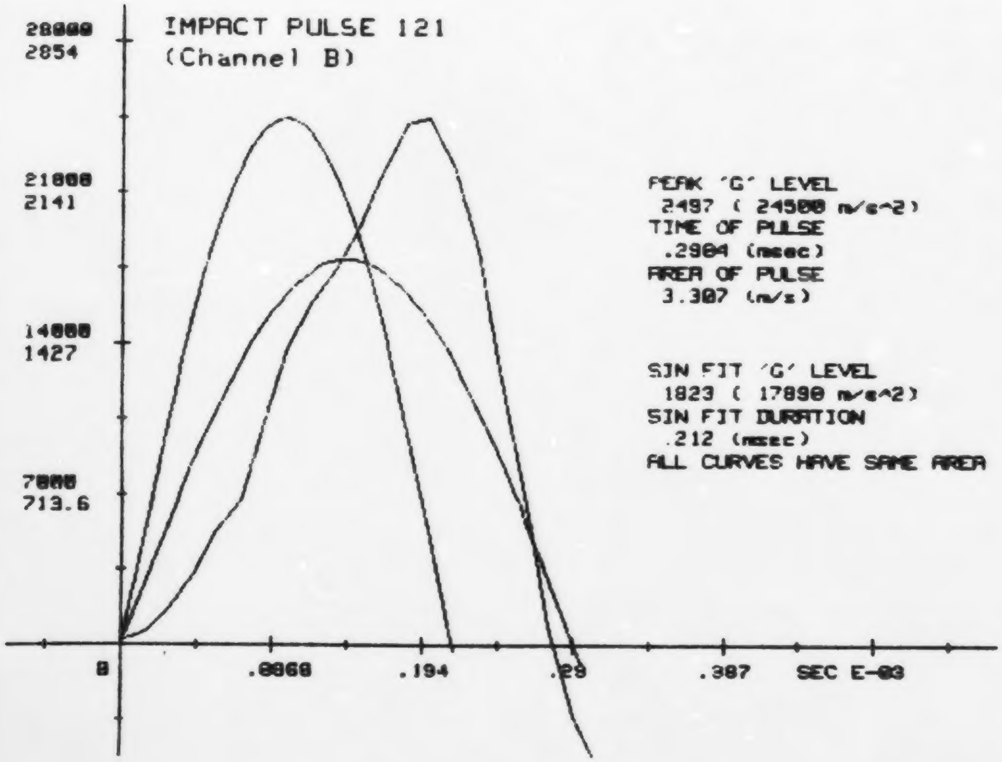
PEAK 'G' LEVEL
3751 (36800 m/s^2)
TIME OF PULSE
.3668 (msec)
AREA OF PULSE
5.258 (m/s)

SIN FIT 'G' LEVEL
2295 (22520 m/s^2)
SIN FIT DURATION
.2244 (msec)
ALL CURVES HAVE SAME AREA



IMPACT PULSE 121
(Channel B)

PEAK 'G' LEVEL
2497 (24500 m/s^2)
TIME OF PULSE
.2904 (msec)
AREA OF PULSE
3.307 (m/s)



IMPACT PULSE 121
(Channel B)

PEAK 'G' LEVEL
2497 (24500 m/s^2)
TIME OF PULSE
.2904 (msec)
AREA OF PULSE
3.307 (m/s)

SIN FIT 'G' LEVEL
1823 (17890 m/s^2)
SIN FIT DURATION
.212 (msec)
ALL CURVES HAVE SAME AREA

APPENDIX "B"

OCEAN RANGER MARINE DISASTER

LIGHT BULB ANALYSIS

B-2

REPORT "E"
ENGINEERING REPORT EP 332/83
BALLAST CONTROL PANEL LIGHT BULB ANALYSIS
8 September 1983

INTRODUCTION

1.1 The Royal Commission investigating the *Ocean Ranger* Marine Disaster requested the Aviation Safety Engineering (ASE) Facility, of the Aviation Safety Bureau, Transport Canada to assist in the investigation by conducting certain tests and analyses on the light bulbs which were removed from the *Ocean Ranger* control panel to determine which bulbs remained functional and which bulbs had experienced damage.

EXAMINATION

2.1 For purposes of analysis, the light bulbs from the control panel were divided into four groups: the port side valve light bulbs labelled P1 through P42, the starboard side valve light bulbs S1 through S42, the port pump lights and the starboard pump lights. The port and starboard valve lights numbered 1 to 42 are housed in switch or indicator assemblies that have a capacity of four bulbs each. Most of the assemblies contained only two bulbs each, one to illuminate the red translucent function plate "closed" and one to illuminate the green translucent plate "open". In the assemblies that contained more than two bulbs only two were wired into the circuit. Therefore the extra bulbs were not examined as part of the system. The port and starboard pump lights indicated which pumps were running by illuminating a green bulb while a red button indicated a stopped pump. The switch assemblies were wired for 24 volts to power the light bulbs and a 115 volt circuit ran alongside the 24 volt circuit to power the valve solenoids. The valve lights numbered 33 to 42 were manual valve indicator lights without switches, and were wired for 24 volts only.

2.2 The bulbs found on the panel were manufactured by various companies (Stanley and Chicago Miniature were most common) and were typically type 387. All of the bulbs found were considered acceptable for use in this application.

2.3 Examination of the bulbs included an optical microscopic evaluation of all filaments. This examination revealed that

TABLE 1

Valve Lights – Port and Starboard

SWITCH	COMMENTS
P3 Open	Fracture – Hot.
P3 Closed	Filament fused to glass in three locations, broken in three places.
P4 Open	Broken hot in one location and fused to glass.
P4 Closed	Broken hot and fused to glass.
P5 Closed	Broken hot and fused to glass in two places.
P6 Open	Broken hot and fused to glass.
P7 Open	Support posts and filament through glass.
P11 Closed	Filament fused to glass.
P12 Closed	Broken hot and fused to glass.
P13 Closed	Broken hot several fragments. Burnout due to combination of age and excessive voltage.
P14 Closed	Broken hot and fused to glass.
P15 Open	Brittle fracture.
P16 Closed	Broken hot and slight fusing.
P19 Closed	Broken hot filament.
P20 Open	Broken from each contact post. Failure probably hot.
P20 Closed	Broken near contact post. Failure probably hot.
P25 Open	(Data not included)
P25 Closed	Filament broken hot. Evidence of melt spots on filament and one brittle fracture.
P27 Closed	Broken hot.
P28 Closed	Filament through glass and support post through glass. Possible burnout.
P28 Open	Filament broken loose inside brittle failures.
P29 Open	Filament broken brittle and fusing.
P31 Open	Filament broken hot.
P33 Open	Broken hot near support post.
P34 Closed	Broken hot.
P35 Open	Broken hot, portions fused to glass envelope.
P35 Closed	Broken hot, pieces fused to glass.
P36 Closed	Broken hot between support posts.
P37 Open	Broken hot.
P38 Open	Several fragments of filament hot.

several of the light bulbs contained fractured filaments, Photo 1 and/or stretched filaments, Photo 2 and/or filaments fused to the glass envelope, Photo 3. All of the bulbs with any type of damage were subsequently examined in the Scanning Electron Microscope (SEM). In most cases of fractured filaments, the filament was broken near its contact post, which is an inherently weak spot in light bulb filaments. SEM analysis of the fracture surfaces revealed that most of the failures exhibited a smooth fracture surface, characteristic of a hot filament at the time of failure, except for eight of the fractures which appeared brittle. Photos 4, 5 and 6 show "hot" fractures or smooth fracture surfaces typical of those found in the *Ocean Ranger*. Table 1 contains a list of all of the bulbs examined that exhibited damage.

DISCUSSION

3.1 The "hot" fractures observed in nearly all of the broken filaments can typically occur as a result of three different mechanisms:

a) severe impact while incandescent;
b) burnout due to old age;
c) burnout due to over-voltage.

The fact that 43 percent of the bulbs failed and that no substantial impact would be expected to have occurred during the rig's sinking suggests that the bulbs were burned out due to over-voltage. Laboratory tests of General Electric type 327 bulbs (similar to the bulbs found in the *Ocean Ranger*) were carried out to determine the effects of high voltage. These tests revealed that the filaments fractured typically near one or both of the contact posts and the filament often fused to the glass envelope. The fracture surfaces were typically smooth and similar to those found in the *Ocean Ranger* control panel. The majority of the bulbs examined from the *Ocean Ranger* did not show signs of excessive age (severe notched appearance) which ruled out burning due to old age. High voltages in tests also caused areas of local filament stretch and as voltage levels were increased, the failures became more explosive, with filaments coming to rest fused to the glass envelope.

3.2 A simulation of the starboard side control panel shown in Photo 7 containing new General Electric type 327 bulbs was flooded with sea water to simulate observed damage to the control panel. The 24 volt circuit fuse blew shortly after and all the lights went out. After some time, lights began to flash

TABLE 1 – (CONT'D)

Valve Lights – Port and Starboard

SWITCH	COMMENTS
P41 Open	Broken hot.
P42 Open	Broken hot and aged.
S2 Closed	Filament fused to glass, water present, severely corroded.
S3 Closed	Filament broken. Support post fused to glass.
S5 Open	Filament broken and fused to glass. Failure looks brittle.
S8 Closed	Filament broken hot. Support touching glass. Evidence of local melting.
S13 Closed	Broken hot.
S14 Open	Possible burnout. Not fracture but stretch.
S14 Closed	Support posts fused. Hot fracture.
S15 Closed	Broken filament hot fused to glass.
S16 Closed	Evidence of local melting, fracture.
S17 Open	Broken hot.
S18 Closed	Broken hot.
S20 Open	Broken filament hot. Posts fused to glass.
S21 Closed	Broken hot.
S22 Closed	Broken hot.
S25 Closed	Broken hot. Fused to glass.
S28 Closed	Broken hot and one brittle fracture. Possible burnout.
S29 Open	Broken hot local melting.
S29 Closed	Broken hot and fused. Local melting.
S30 Closed	Broken hot and fused. Brittle failure found.
S31 Closed	Broken hot and fused.
S32 Open	Broken brittle and fused.
S32 Closed	(Data not included)
S33 Open	Broken hot.
S34 Open	Broken hot.
S34 Closed	Broken hot.
S37 Open	Broken hot.
S37 Closed	Broken hot.
S38 Open	Broken hot.
S39 Open	Broken hot.

B-4

on randomly with varying high intensity. Of the bulbs examined in the simulation panel approximately 80% revealed damage characteristic of a burnout due to over-voltage. Photos 8 and 9 show filaments from the simulation panel. Photo 8 shows filament stretch similar to that shown in Photo 2 from the actual panel. Photo 9 shows local enlargement of the filament cross section similar to the over-voltage test results depicted in Photo 10 and similar to Photo 4 of the actual panel. Local enlargement of the filament wire near the fracture was not as apparent in the actual *Ocean Ranger* bulbs, possibly because of the age of the filaments. It is possible that the 24 volt circuit blew and the 115 volt circuit arced with the aid of the water, causing the bulbs to see voltages well in excess of 24 volts in the actual *Ocean Ranger* panel as well as in the simulation panel. The light bulbs listed in Table 1 were probably subjected to voltage surges well in excess of 24 volts.

CONCLUSIONS

4.1 The light bulbs were considered to be standard light bulbs for this type of application on a 24 volt circuit.

4.2 The 76 bulbs listed in Table 1 appear to have suffered heat damage, probably due to voltage surges well in excess of 24 volts.

4.3 Eight of the bulbs in Table 1 contained both brittle fractures and evidence of fusing and melting, and were considered burned out also.

4.4 Twenty-three of the bulbs contained filaments and/or support posts fused to the glass envelope indicative of over-voltage or intense heat.

4.5 Figures 1 and 2 are diagrams of the *Ocean Ranger* panel showing the bulbs that were considered to be damaged due to over-voltage and Figure 3 contains a diagram of the simulation panel (starboard panel only) showing the bulbs that were damaged due to over-voltage.

TABLE 1 (CONT'D)

Pumplights—Starboard

SWITCH	COMMENTS
#2 B.W. STOP	Filament fused to glass.
#4 B.W. STOP	Aged and broken hot.
#6 B.W. RUN	Aged and broken hot.
#2 BILGE STOP	Aged broken hot.
#4 BILGE STOP	Aged broken hot.
#2 DRILL STOP	Broken hot.
S39 Closed	Broken hot.
S41 Open	Broken hot.
S42 Open	Broken hot.

Pumplights – Port

SWITCH	COMMENTS
#1 B.W. STOP	Aged and broken hot.
#3 B.W. STOP	Aged and broken hot.
#5 B.W. STOP	Fused and broken hot.
#1 BILGE STOP	Aged and broken hot.
#3 BILGE STOP	Aged and broken hot.
#1 D.W. STOP	Aged and broken hot.

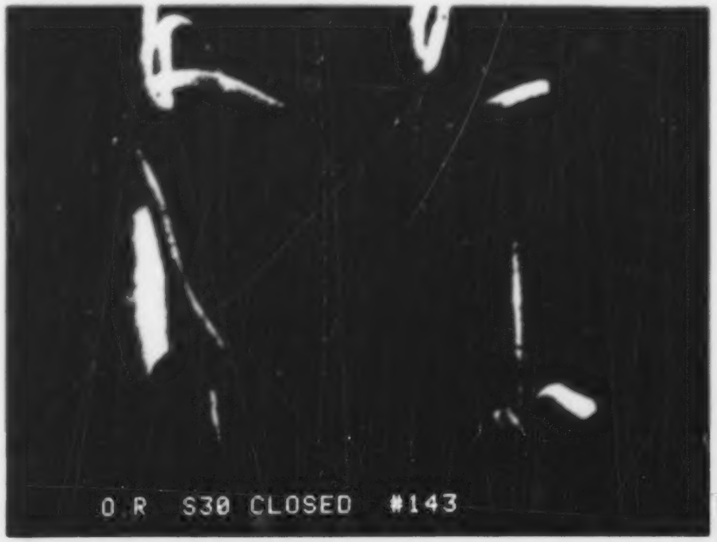

O R S30 CLOSED #143

PHOTO 1 Starboard #30 closed. Filament broken near contact post.

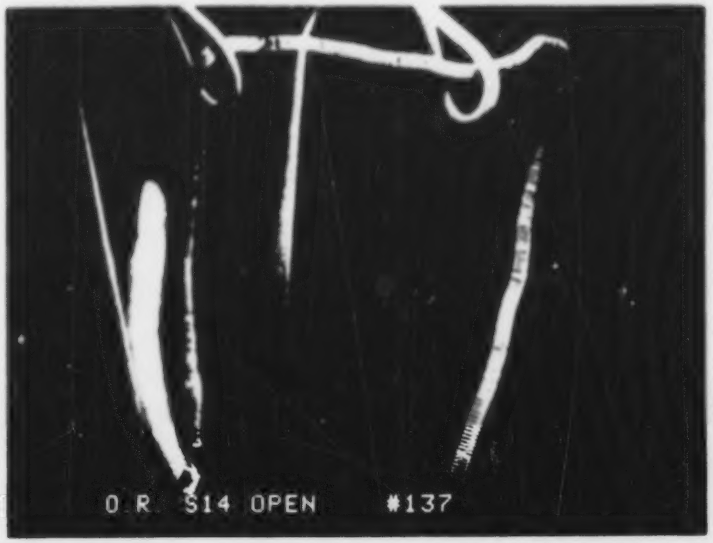

O R S14 OPEN #137

PHOTO 2 Stretched filament damage probably due to high voltage.

PHOTO 3 Filament fused to glass from #2 bilge water starboard *stop* pumplight.

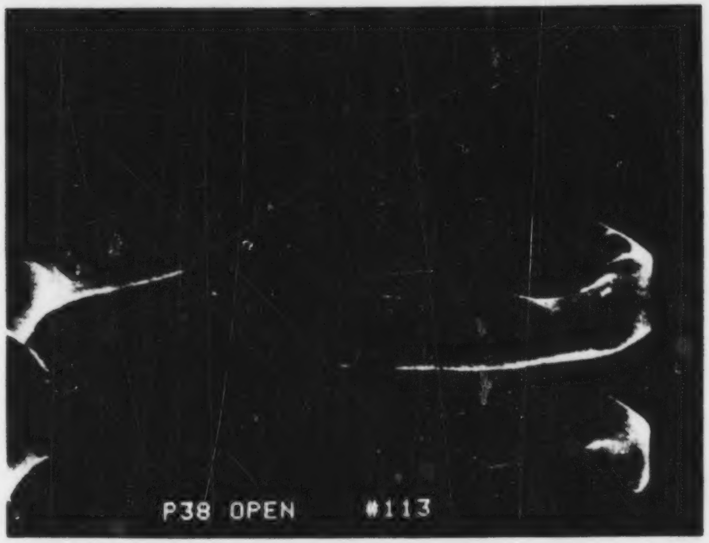

P38 OPEN #113

PHOTO 4 Hot fracture of port #38 open bulb.

B.5

B-6

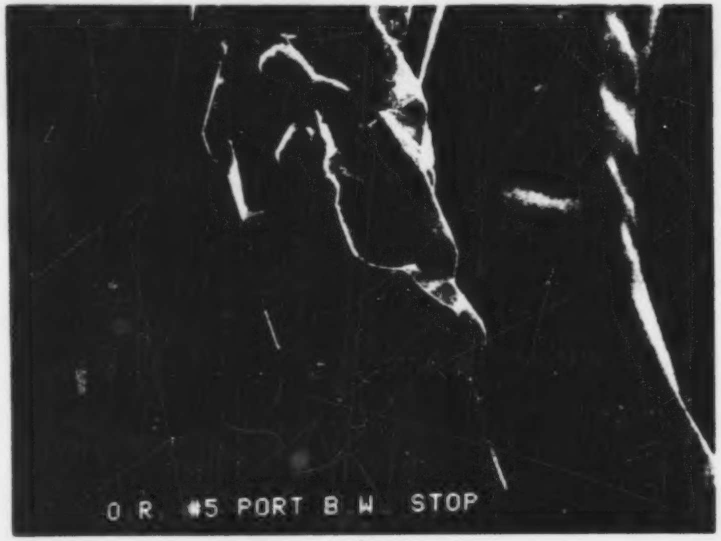

O R #5 PORT B W STOP

PHOTO 5 Smooth fracture surface of port ballast water stop bulb.

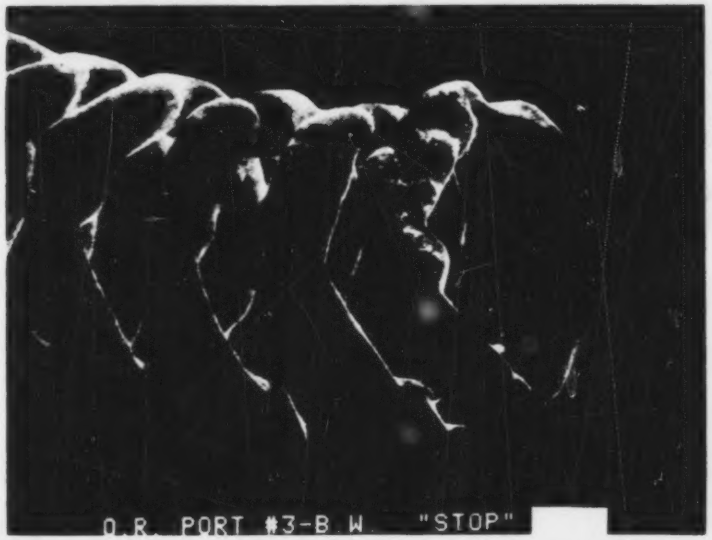

O.R. PORT #3-B W "STOP"

PHOTO 6 Smooth fracture surface of port #3 ballast water stop.

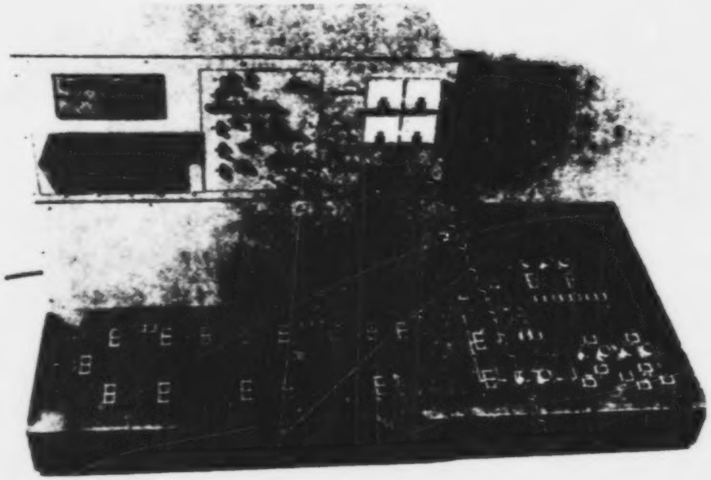


PHOTO 7 Simulation control panel of the *Ocean Ranger*.

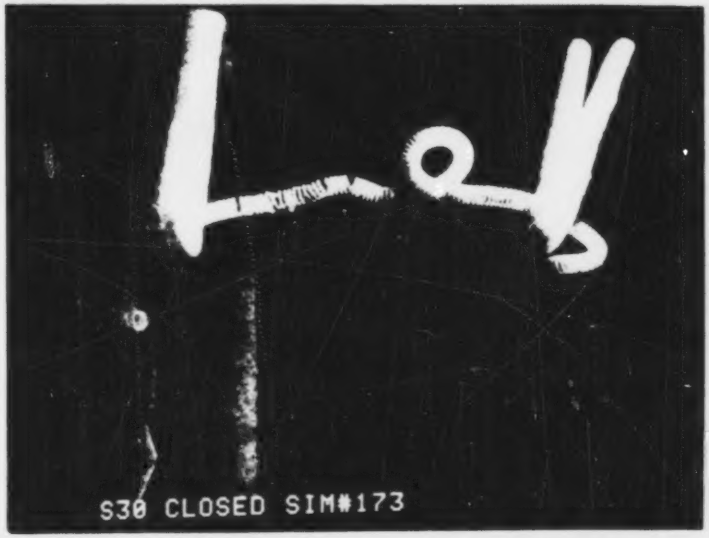
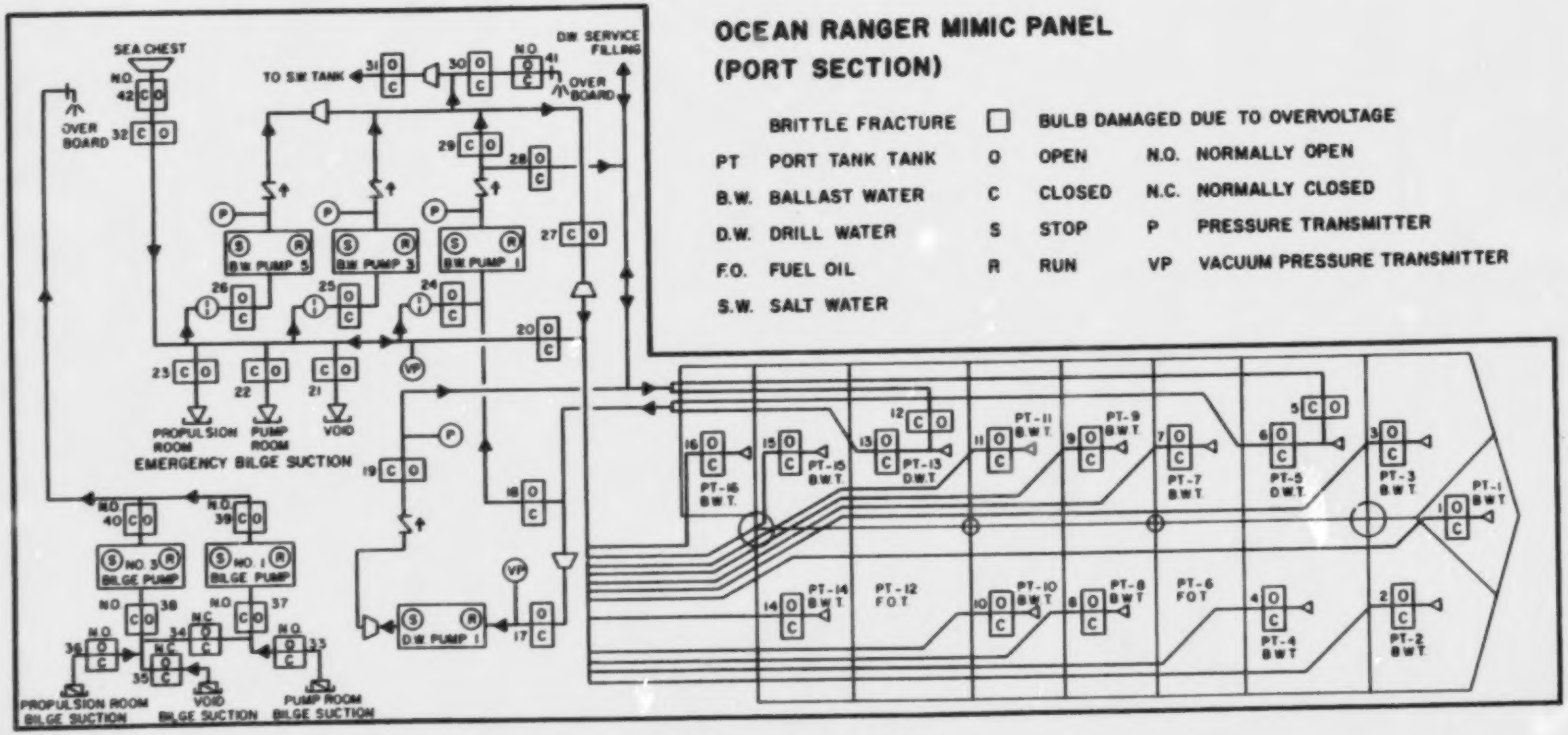

S30 CLOSED SIM#173

PHOTO 8 Filament from simulation panel flooded with water.


SEA CHEST
N.O.
42
OVER BOARD
32
TO S.W. TANK
31
30
N.O.
41
OVER BOARD
D.W. SERVICE FILLING
29
28
27
P
S
R
B.W. PUMP 5
B.W. PUMP 3
B.W. PUMP 1
26
25
24
20
23
22
21
VP
PROPULSION ROOM
PUMP ROOM
VOID
EMERGENCY BILGE SUCTION
19
18
N.O.
40
N.O.
39
NO. 3 BILGE PUMP
NO. 1 BILGE PUMP
N.O.
38
N.O.
37
N.C.
34
N.O.
36
N.C.
35
N.O.
33
PROPULSION ROOM BILGE SUCTION
VOID BILGE SUCTION
PUMP ROOM BILGE SUCTION
D.W. PUMP 1
17
16
PT-16 B.W.T.
15
PT-15 B.W.T.
13
12
PT-13 D.W.T.
11
PT-11 B.W.T.
9
PT-9 B.W.T.
7
PT-7 B.W.T.
6
5
PT-5 D.W.T.
3
PT-3 B.W.T.
1
PT-1 B.W.T.
14
PT-14 B.W.T.
PT-12 F.O.T.
10
PT-10 B.W.T.
8
PT-8 B.W.T.
PT-6 F.O.T.
4
PT-4 B.W.T.
2
PT-2 B.W.T.
O
C

OCEAN RANGER MIMIC PANEL
(PORT SECTION)

	BRITTLE FRACTURE	☐	BULB DAMAGED DUE TO OVERVOLTAGE		
PT	PORT TANK TANK	O	OPEN	N.O.	NORMALLY OPEN
B.W.	BALLAST WATER	C	CLOSED	N.C.	NORMALLY CLOSED
D.W.	DRILL WATER	S	STOP	P	PRESSURE TRANSMITTER
F.O.	FUEL OIL	R	RUN	VP	VACUUM PRESSURE TRANSMITTER
S.W.	SALT WATER				

FIGURE 1 Port Mimic Panel.

B-8

OCEAN RANGER MIMIC PANEL
(STARBOARD SECTION)

	BRITTLE FRACTURE	☐	BULB DAMAGED DUE TO OVERVOLTAGE		
ST	STARBOARD TANK	O	OPEN	N.O.	NORMALLY OPEN
B.W.	BALLAST WATER	C	CLOSED	N.C.	NORMALLY CLOSED
D.W.	DRILL WATER	S	STOP	P	PRESSURE TRANSMITTER
F.O.	FUEL OIL	R	RUN	VP	VACUUM PRESSURE TRANSMITTER
S.W.	SALT WATER				

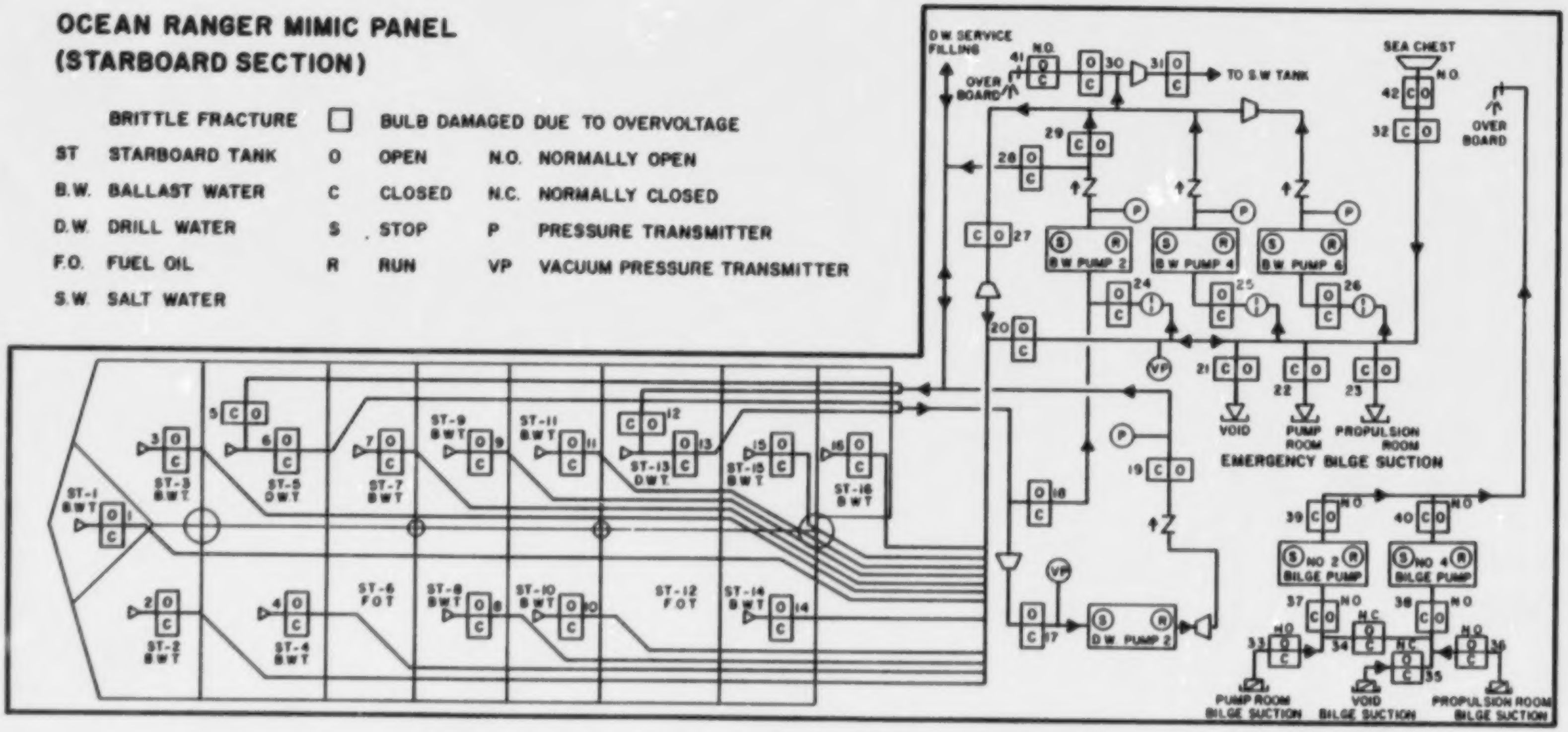

D.W. SERVICE FILLING
OVER BOARD
N.O.
TO S.W TANK
SEA CHEST
OVER BOARD
B.W PUMP 2
B.W PUMP 4
B.W PUMP 6
VOID
PUMP ROOM
PROPULSION ROOM
EMERGENCY BILGE SUCTION
NO 2 BILGE PUMP
NO 4 BILGE PUMP
D.W. PUMP 2
N.C.
PUMP ROOM BILGE SUCTION
VOID BILGE SUCTION
PROPULSION ROOM BILGE SUCTION
ST-1 BWT
ST-2 BWT
ST-3 BWT
ST-4 BWT
ST-5 DWT
ST-6 FOT
ST-7 BWT
ST-8 BWT
ST-9 BWT
ST-10 BWT
ST-11 BWT
ST-12 FOT
ST-13 DWT
ST-14 BWT
ST-15 BWT
ST-16 BWT
O
C
S
R
P
VP

FIGURE 2 Starboard Mimic Panel.

S30 CLOSED SIM#173

PHOTO 9 Filament from simulation panel flooded with water.

HIGH SPEED TEST #14 S130

PHOTO 10 Filament experiencing 70 volts AC in the laboratory.

OCEAN RANGER SIMULATION PANEL
(STARBOARD SECTION ONLY TESTED PUMP SWITCHES NOT INCLUDED IN TEST)

ST	STARBOARD TANK	☐	BULB DAMAGED DUE TO OVERVOLTAGE		
B.W.	BALLAST WATER	O	OPEN	N.O.	NORMALLY OPEN
D.W.	DRILL WATER	C	CLOSED	N.C.	NORMALLY CLOSED
F.O.	FUEL OIL	S	STOP	P	PRESSURE TRANSMITTER
S.W.	SALT WATER	R	RUN	VP	VACUUM PRESSURE TRANSMITTER

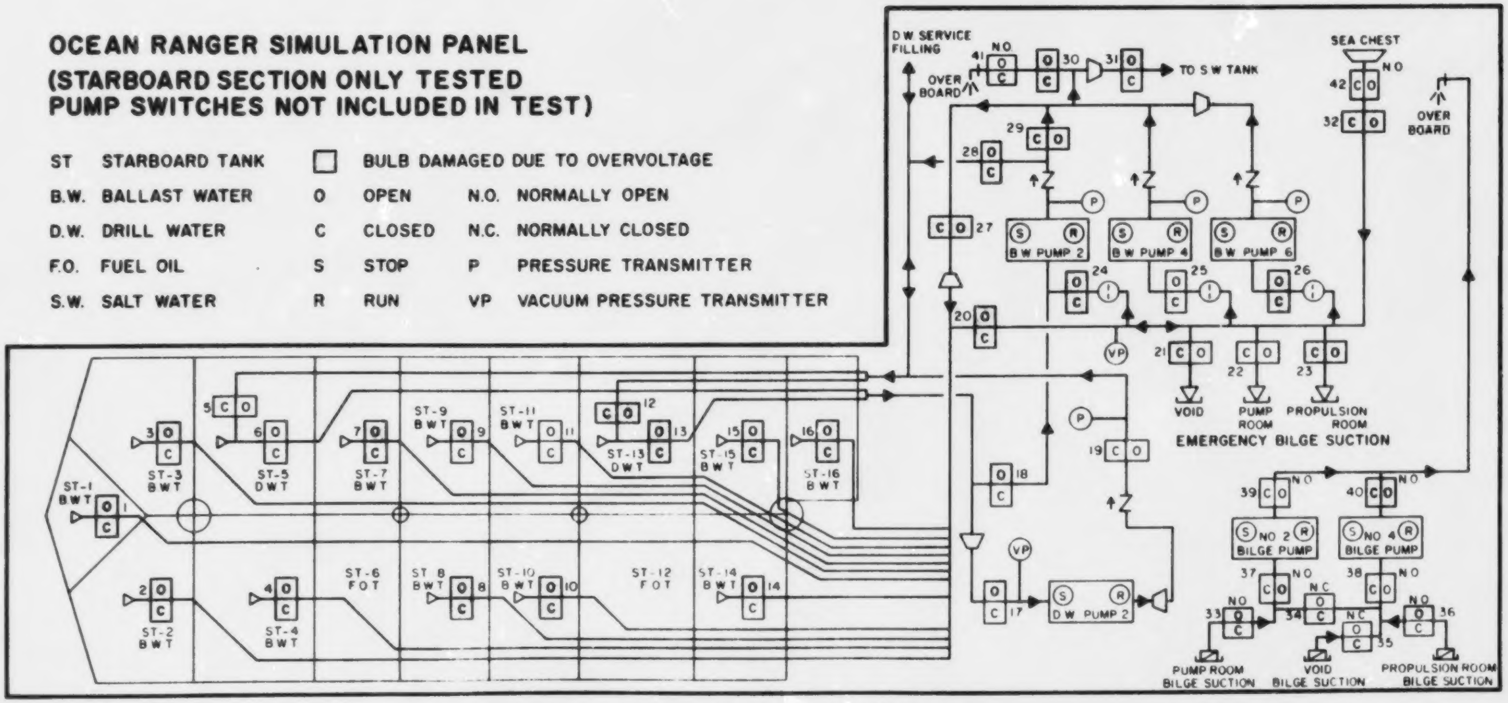

D W SERVICE FILLING
OVER BOARD
NO
TO S W TANK
SEA CHEST
OVER BOARD
B W PUMP 2
B W PUMP 4
B W PUMP 6
D W PUMP 2
NO 2 BILGE PUMP
NO 4 BILGE PUMP
VOID
PUMP ROOM
PROPULSION ROOM
EMERGENCY BILGE SUCTION
PUMP ROOM BILGE SUCTION
VOID BILGE SUCTION
PROPULSION ROOM BILGE SUCTION
N C
ST-1 BWT
ST-2 BWT
ST-3 BWT
ST-4 BWT
ST-5 DWT
ST-6 FOT
ST-7 BWT
ST 8 BWT
ST-9 BWT
ST-10 BWT
ST-11 BWT
ST-12 FOT
ST-13 DWT
ST-14 BWT
ST-15 BWT
ST-16 BWT

FIGURE 3 Starboard Mimic Panel (Simulator).

APPENDIX "C"

ACTUAL CRASH ANALYSIS

1. Rotating Beacon C-2
2. Annunciator Panel C-10

C-2

CANADIAN AVIATION SAFETY BOARD
AVIATION SAFETY ENGINEERING FACILITY

BUREAU CANADIEN DE LA SECURITE AERIENNE
FACILITÉ DE L'INGÉNIÉRIE DE LA SÉCURITÉ AÉRIENNE

ENGINEERING REPORT
RAPPORT TECHNIQUE

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			2
			APPENDICES – *ANNEXES*
5002-82-H40004	2	6	

ENGINEERING REPORT
RAPPORT TECHNIQUE LP 384/84

ANALYSIS OF ROTATING BEACON

DeHavilland DHC-6,100, C-FPPL

PROJECT OFFICER(S) – *AGENT(S) DE PROJET*

M.R. Poole (Electrical/Mechanical Research Specialist)

SUBMITTED BY – *PRÉSENTÉ PAR*

M. Vermij (Supervisor, Electrical/Mechanical Engineering Analysis)
R.K. McLeod (Superintendent, Engineering Analysis)

APPROVED – *APPROUVÉ*

R.G. Hayman (Director)

DATE COMPLETED—*TERMINÉ LE*

7 Jan 85

23-0022
(12-77)

C-3

1.0 INTRODUCTION

1.1 On October 9, 1984, a Dehavilland DHC-6, C-FPPL, reportedly hit a communication tower and sheared 15 feet of its right wing. The aircraft subsequently impacted the ground inverted.

1.2 The rotating beacon was removed from the wreckage and forwarded to Aviation Safety Engineering (ASE) from PASI along with a request to determine if the beacon light was on or off at the moment of ground impact.

2.0 EXAMINATION

2.1 Photo 1 shows the rotating beacon as received at ASE. The large red envelope protects two light bulbs that rotate within the assembly. Photo 2 shows the top rotating lights with the red shield removed. The rotating light assembly was labelled part number G-7740A, serial number 26778, operated on 28 volts d.c. and was manufactured by Grimes Manufacturing of Urbana, Ohio. The two light bulbs found were labelled G-12 TH and G-12 UB, both manufactured by Grimes.

2.2 Both light bulbs had broken glass envelopes which had shattered into hundreds of small fragments. Some small pieces of glass envelope can be seen in Photo 2. Three large segments of filament were also found amoungst the shattered glass. All of the pieces of filament examined, including the ones still attached to the bulbs, exhibited severe stretch.

2.3 The filament fragments and two light bulbs were removed from the assembly and examined in the scanning electron microscope (SEM). Photo 3 shows a general SEM image of one of the filament fragments illustrating the severly stretched coil. Close examination of all the filament segments revealed that a foreign material had adhered to the filament surface, which had subsequently developed cracks (see Photo 4). Energy dispersive X-ray (EDX) analysis revealed the adhered material (area "b" of Photo 4) to be derived from the tungsten of the base material. Similar spectra were obtained from comparative analysis of the coating and underlying substrate, differing only in count rates and peak heights (Figure 1 depicts the spectral plot for the adhered material and base material). These differences are attributed to lower atomic number compounds, likely a result of oxides in the adhered material, which accounts for the difference in peaks between curves "a" and "b" of Figure 1. Further energy dispersive X-ray analysis revealed that particles of the glass envelope had fused to the filament surface (see Photos 5 and Figure 2).

C-4

2.4 Photo 6 shows the fracture surface of one of the filament segments which exhibited considerable necking.

3.0 DISCUSSION

3.1 The severe filament stretch found in both bulbs of the rotating beacon is evidence that the beacon was incandescent (on) at the time of impact. SEM and EDX analysis revealed that an oxide layer had formed around the filament, which is characteristic of an incandescent filament being exposed to the atmosphere, i.e. when the glass envelope shattered. Particles of glass envelope were found fused to the filament surface, also characteristic of a hot filament. The necked fracture surface of Photo 6 is further evidence of a hot filament at the time of failure.

4.0 CONCLUSIONS

4.1 The two light bulbs from the top rotating beacon exhibited severely stretched filaments, with an oxide layer encasing the filament, particles of glass envelope fused to the filament, and necked fractures; all of these phenomena are characteristic of an incandescent filament at impact. The top rotating beacon was therefore "on" at impact.

TRACOR-NORTHERN SPECTRAL PLOT

1ST HALF: LP 384/84 FILAMENT SURFACE LT= 100 SECS 0.020 KEV
2ND HALF: LP 384/84 "MUD CRACK" DEPOSITS LT= 100 SECS 0.020 KEV

COUNTS F.S.=16384

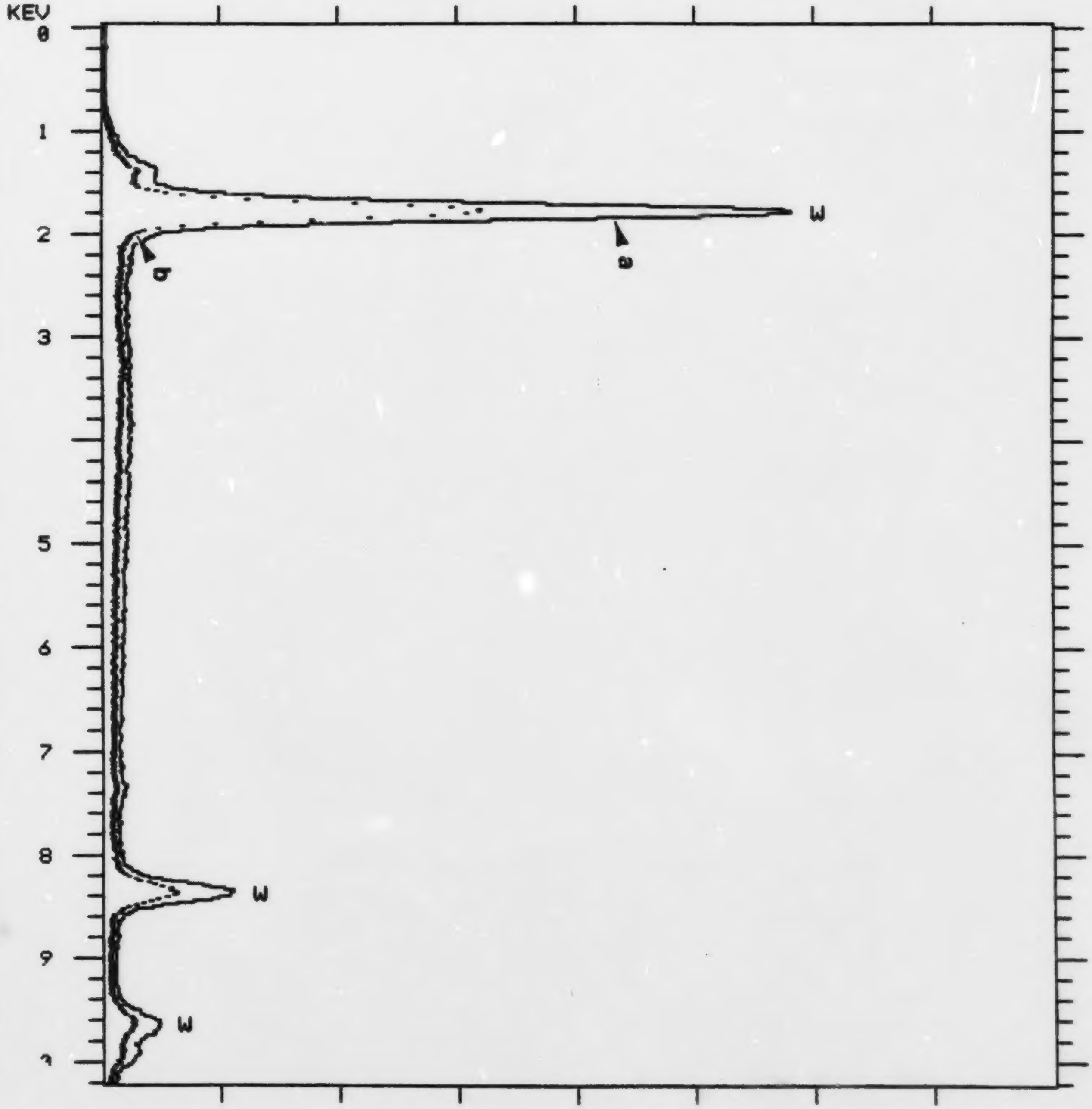

FIGURE 1 : Refer to Photo 4.

TN FLEXTRAN [11-E]

SDMP2-2A/80 SPEC.PLT

TRACOR-NORTHERN SPECTRAL PLOT

1ST HALF: LP 384/84 GLOBULAR PARTICLES LT= 200 SECS 0.020 KE

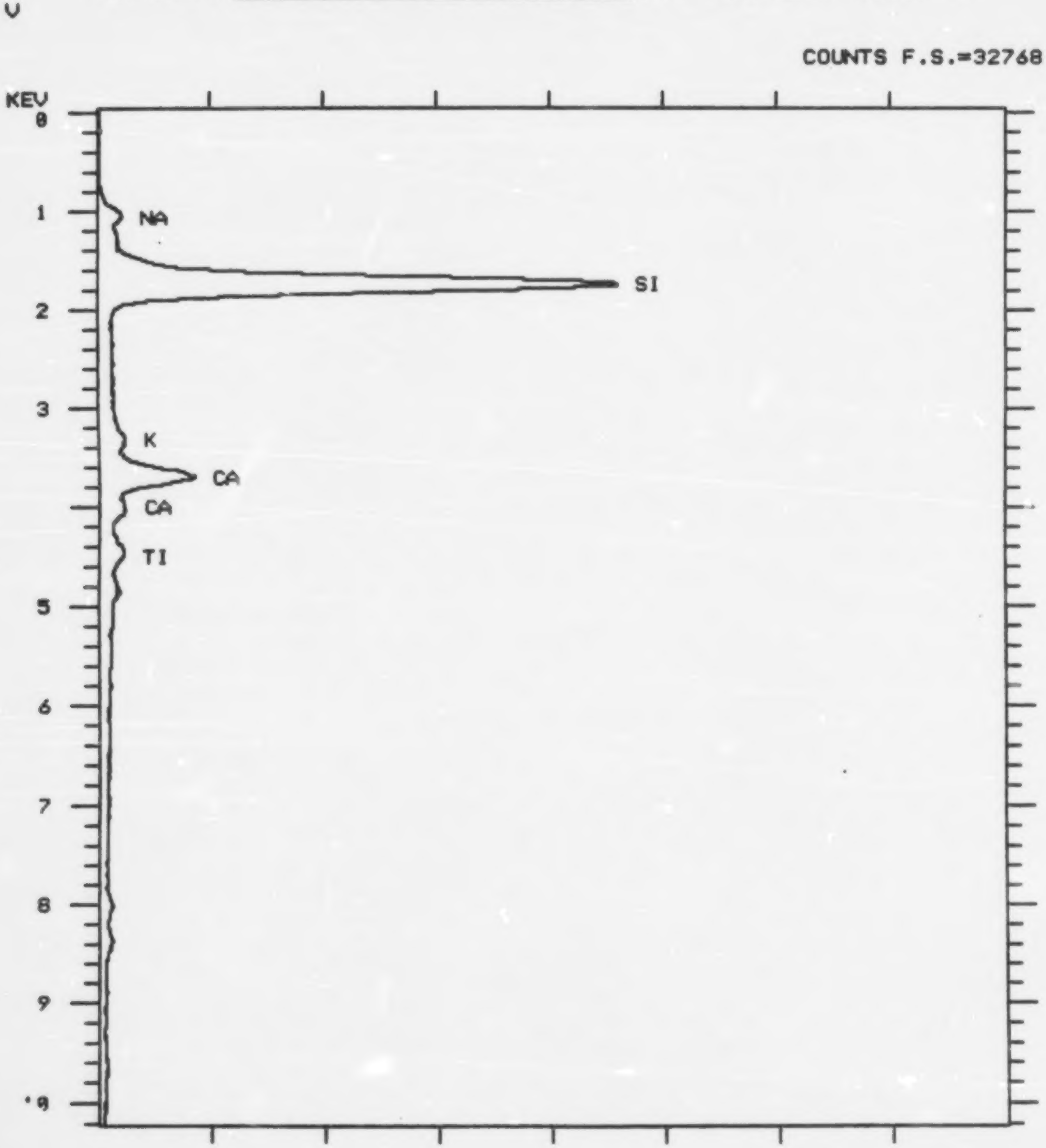

FIGURE 2: Refer to Photo 5.

PHOTO 1 - TOP ROTATING BEACON AS-RECEIVED AT ASE.

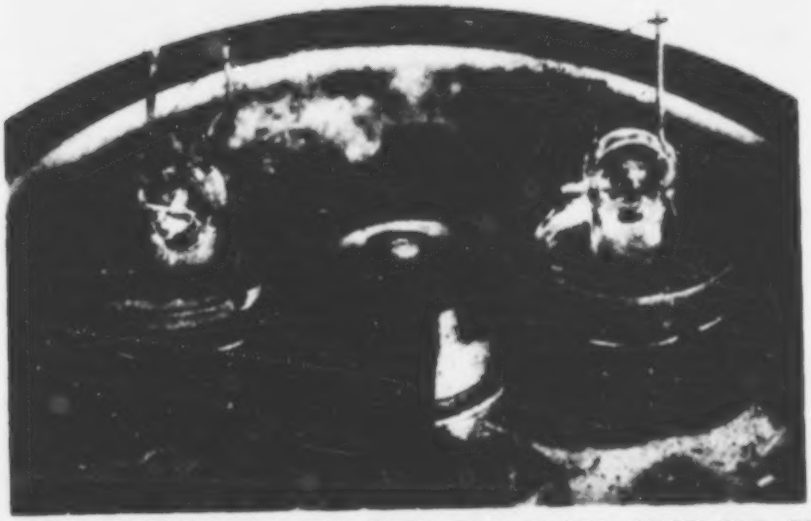

PHOTO 2 - TOP ROTATING BEACON WITH RED GLASS ENVELOPE REMOVED REVEALING TWO GRIMES G12 LIGHT BULBS WITH BROKEN GLASS ENVELOPES.

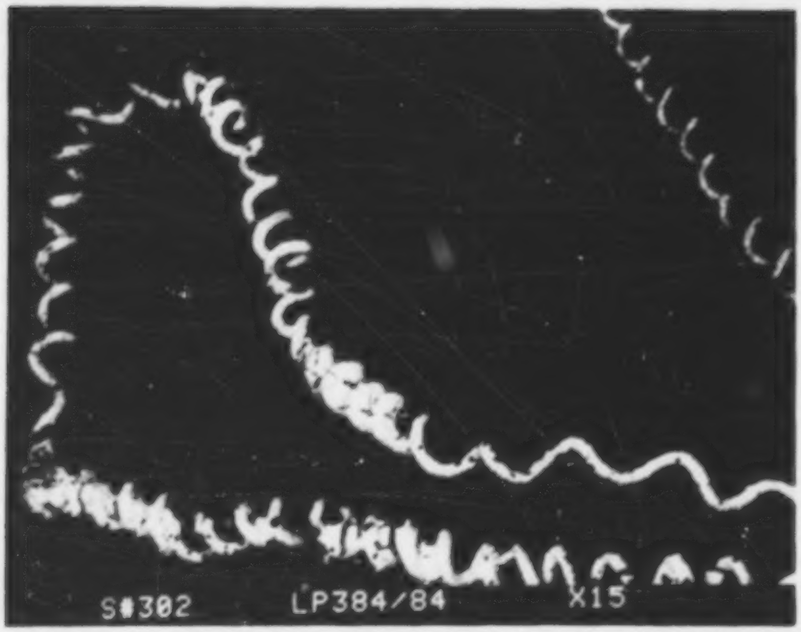
S#302
LP384/84
X15

PHOTO 3 - SEVERELY STRETCHED CONDITION OF ONE OF THE FRAGMENTS OF FILAMENT FOUND IN AMONGST THE SHATTERED GLASS.

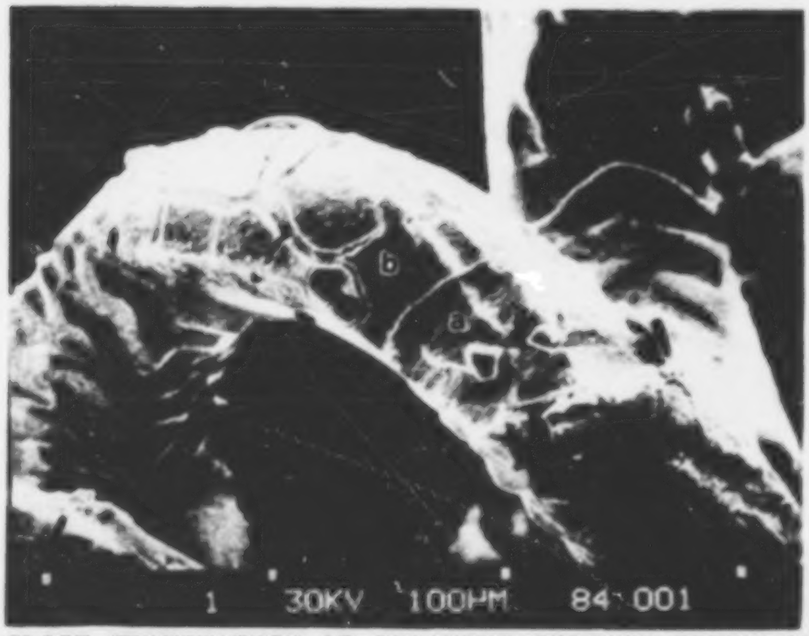
b
a
1
30KV
100μM
84 001

PHOTO 4 - CLOSE EXAMINATION OF FILAMENT SURFACE REVEALED ADHERENT AND CRACKED FOREIGN MATERIAL. FIGURE "A" CONTAINS ENERGY DISPERSIVE X-RAY ANALYSIS OF AREAS LABELLED "A" AND "B".

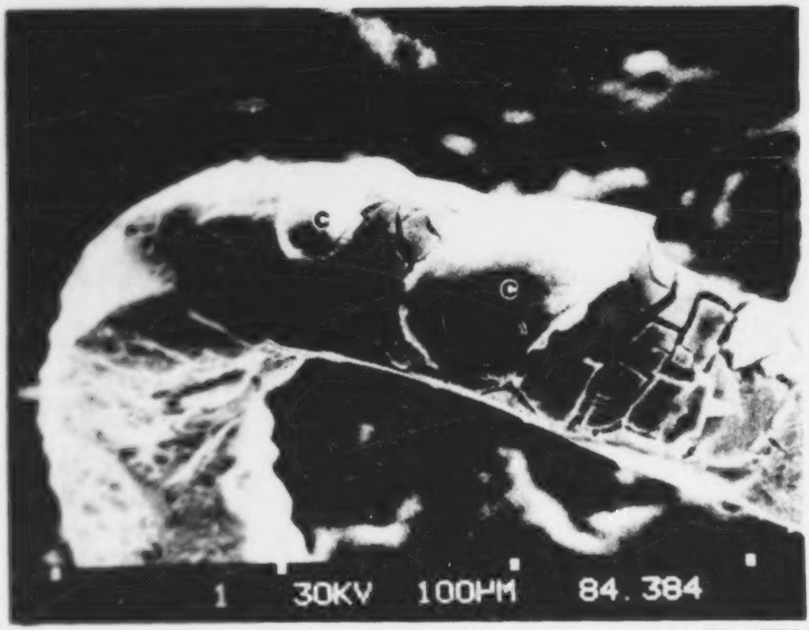
C
C
1 30KV 100µM 84.384

PHOTO 5 - ENERGY DISPERSIVE X-RAY ANALYSIS REVEALED THAT THE PARTICLES LABELLED "C" WERE LARGELY COMPOSED OF SILICON, A DERIVITIVE OF THE GLASS ENVELOPE.

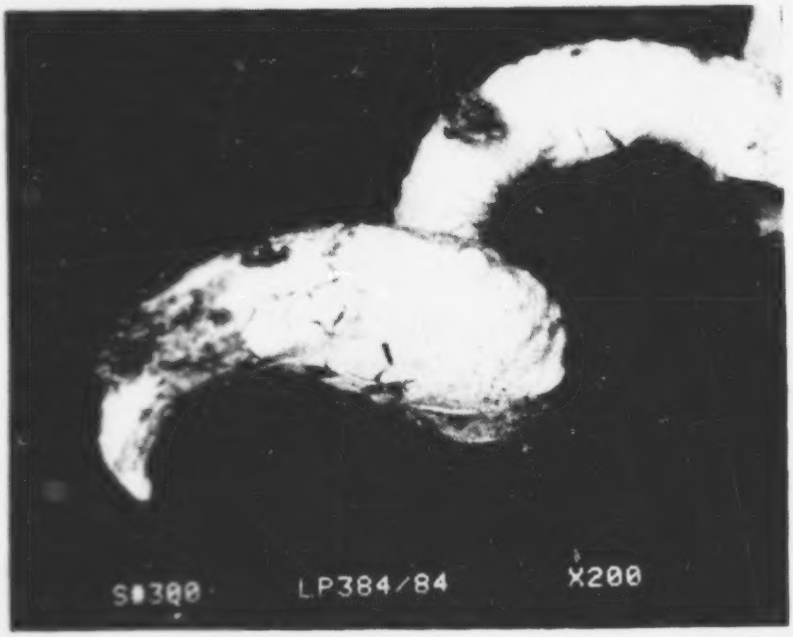
S#300
LP384/84
X200

PHOTO 6 - NECKED FRACTURE SURFACE FOUND ON ONE OF THE FILAMENT SEGMENTS.

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CANADIAN AVIATION SAFETY BOARD
AVIATION SAFETY ENGINEERING FACILITY

BUREAU CANADIEN DE LA SECURITE AERIENNE
FACILITÉ DE L'INGÉNIÉRIE DE LA SÉCURITÉ AÉRIENNE

ENGINEERING REPORT
RAPPORT TECHNIQUE

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			1
			APPENDICES – *ANNEXES*
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ENGINEERING REPORT
RAPPORT TECHNIQUE LP 342/84

ANNUNCIATOR PANEL ANALYSIS

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DATE COMPLETED – *TERMINÉ LE*

16 Jan 85

23-0022
(12-77)

C-11

1.0 INTRODUCTION

1.1 A Cessna Citation, C-GXFZ, reportedly dove from approximately 1000 feet above ground level into swampy, tree covered terrain, and was totally destroyed. The aircraft's annunciator panel, mode panel, and "MASTER WARNING" indicator were retrieved from the wreckage by OASI and forwarded to Aviation Safety Engineering (ASE) along with a request to determine which indicator lights were "on" at impact.

2.0 EXAMINATION

2.1 Photos 1 and 2 show the annunciator panel and mode panel respectively as received at ASE, with the indicators numbered for reference. The annunciator panel provided space for two type 327 sub-miniature light bulbs for illumination of each of the 30 functions on the panel. More than one half of the bulbs from the annunciator panel were manufactured by General Electric while the remainder were manufactured by Carley Lamps. The indicator/switches from the mode panel each contained four type 377 bulbs manufactured by Chicago Miniature, except for the "FD" indicator/switch which contained four General Electric type 328 bulbs. The indicator/switches from the mode panel are subdivided to illuminate various messages within the indicator/switch as shown in Figure 1. The "HDG", "TURB", "ALT, "GS", and "NAV" indicator/switches were found to be in the "pushed in" position as identified in Figure 1. The "MASTER WARNING" indicator contained four General Electric type 327 bulbs. The glass envelopes which encased the filament in a vacuum were found to be intact except for one of the bulbs from the "MASTER WARNING", one of the bulbs from the "TURB" mode panel indicator/switch and one of the bulbs from a mode panel indicator/switch later identified as "BACKCOURSE". The external damage to both panels and to the "Master Warning" indicator was quite severe.

2.2 All of the light bulbs were examined under the stereo-optical microscope and/or scanning electron microscope (SEM). Appendix "A" contains a list of all the bulbs examined along with observations and conclusions. The functions of some of the bulbs were initially unknown as the face plate was destroyed or lost during the crash; however, they were later identified via diagrams and observations of a "sister" aircraft.

2.3 The "F/D AC PWR FAIL", "HYD PRESS ON", and "DOOR NOT LOCKED" contained bulbs which exhibited severe filament deformation and uncoiling as seen in Photos 3 through 7. The second bulb from the "F/D AC PWR FAIL" did not show filament deformation and was found to have fractured into several small fragments (see Photo 8). Photos 9 and 10 show two representative bulbs from the "MASTER WARNING" indicator which also exhibited excessive filament deformation and uncoiling. The third bulb was in a similar condition to that of Photos 9 and 10 while the fourth bulb had a broken glass envelope with the entire filament missing.

2.4 The "L HYD PRESS LO" contained two bulbs which exhibited moderate filament deformation and uncoiling, but not as severe as the bulbs described above. One of the bulbs from the "L HYD PRESS LO" is shown in Photo 11. The second bulb was in a similar condition. The "R HYD PRESS LO", "HYD LEVEL LO", "R ENG ICE FAIL", "L FUEL PRESS LO" and an annunciator panel indicator subsequently identified as "R FUEL BOOST ON" all contained some bulbs with slightly deformed filaments and slight uncoiling. A representative of one of these bulbs is shown in Photo 12. The remaining bulbs from the annunciator panel contained fractured filaments or completely 'shattered' filaments which remained essentially tightly coiled (Photo 13). Some small amounts of stretch were found in some of those bulbs as outlined in Appendix A.

2.5 The bulbs from the mode panel were of a different configuration than those of the annunciator panel and "MASTER WARNING" indicator, in that they contained no support posts to suspend the filament. The filament configuration for the type 327 bulbs is known as "C-2F" while the bulbs from the mode panel are known as "C-2R". The C-2R configuration consists of a shorter filament running in a slight arc between the two contact or terminal posts, while the C-2F has a much longer filament suspended by the two support posts.

2.6 All four of the bulbs from the "ALT" indicator/switch of the mode panel contained segments of filament that had fused to the glass envelope (see Photo 14). One of the bulbs from the "HDG" indicator/switch is shown in Photo 15, and it also had a filament fragment adhering to the glass envelope. This bulb was from the top portion of the indicator/switch that illuminates the letters "HDG". The second bulb from the top portion of the "HDG" indicator" switch is shown in Photo 16 and exhibited severe filament stretch but no fracture. One of the bulbs from a mode panel indicator/switch subsequently identified as "BACK COURSE" contained small pieces of filament fused to the glass and a bulb with a broken glass envelope which exhibited a severely stretched segment of filament. Analysis of this portion of filament was difficult due to the excessive contamination on the filament surface. The remaining bulbs from the

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mode panel contained some bulbs exhibiting moderate amounts of filament deformation and/or fractures, but no evidence of any filament segments melted into the glass envelope.

2.7 SEM analysis revealed no evidence of molten tungsten in any of the fractures examined and also revealed evidence indicating none of the filaments were "new". Most of the bulbs examined in the SEM contained small amounts of filament notching characteristic of a relatively low burning time (see Appendix "A" for comments on filament age).

3.0 DISCUSSION

3.1 The severe filament deformation and uncoiling found in the bulbs of the "F/D AC PWR FAIL", "HYD PRESS ON", "DOOR NOT LOCKED", and the "MASTER WARNING" indicators were considered characteristic of a hot filament subjected to a severe impact. These bulbs were not "new" in terms of filament age, hence the severe filament stretch found could only have occurred while the bulb was hot. Tests on GE-327 bulbs have shown that a cold filament with minimal age tends to fracture without showing filament stretch or uncoiling when cold. Although the second bulb from the "F/C AC PWR FAIL" did not exhibit typical characteristics of a hot filament at impact, the indicator was still considered "on" at impact. This latter bulb may have failed prior to impact, but the filament was too badly shattered to yield any definitive evidence. The two bulbs of the "L HYD PRESS LO" contained filaments exhibiting moderate stretch or deformation and less uncoiling than those described above. This indicator was probably "on" at impact.

3.2 The severity of the damage found in examining these lights indicate that they experienced an extremely severe impact. Laboratory impact tests up to 4000 g (over 0.7 millisecond half-sine pulse) using similarly aged test bulbs did not produce damage as severe as found in this crash, suggesting that the Citation bulbs saw greater impact forces. Impact in this higher range is not, as yet, as well studied by ASE. The "R HYD PRESS LO" and "R FUEL BOOST ON", both contained bulbs exhibiting moderage filament deformation and uncoiling when compared to those described above. As these bulbs were found to be relatively new in terms of filament age, and due to the severity of the impact, it is possible that this damage occurred while the filament was cold. However, ASE was not able to conclusively determine the impact state of these particular bulbs. The remaining bulbs of the annunciator panel exhibited little or no significant filament deformation other than fractures and were all considered "off" at impact.

C-14

3.3 The light bulbs of the mode panel were of the C-2R configuration. This type of light bulb has not, as yet, been fully fully investigated by ASE in terms of laboratory impact tests. The lack of support posts (that can 'whip' the filament around at impact) and the shorter filament length allow this type of bulb to generally withstand greater impact than the C-2F configuration. All of the bulbs from the "ALT" mode indicator/-switch and the two top bulbs of the "BACK COURSE" mode contained filament fragments fused to the glass envelope. Obviously these bulbs were incandescent at impact. The "HDG" mode indicator/switch contained one of the top bulbs again with filament fragments melted into the glass envelope and the second top bulb contained severe filament stretch. Hence, the top portions of the "HDG" and "BACK COURSE" indicator/switches and the entire "ALT" indicator/switch were considered "on" at impact. The remaining bulbs from the mode panel contained filaments exhibiting deformation and/or fracture evidence from which again ASE was not able to determine impact state, due to the nature of the bulb and impact severity.

3.4 The aircraft was reportedly travelling at 270 knots prior to impact in a near vertical attitude. The time from initial nose contact to annunciator panel impact would therefore be only a few milliseconds. Since laboratory tests have shown that it takes approximately 50 milliseconds for a GE-327 bulb to reach incandescence once power is applied, it is not likely that the "on" indications were false resulting from the bulb being "shorted" during the impact sequence.

3.5 SEM fracture analysis revealed no obvious hot fractures (i.e. molten tungsten); however laboratory tests show this is not unusual. Molten tungsten typically only occurs when the filament crosses together or sees excess voltage, which escalates the filament temperature above its melting point (3410°C).

4.0 CONCLUSIONS

4.1 The "F/D AC PWR FAIL", HYD PRESS ON", "DOOR NOT LOCKED," "MASTER WARNING", "ALT", top portion of "HDG" and top portion of "BACKCOURSE" all contained damage consistent with a hot filament subjected to a severe impact, and were considered "on" at impact.

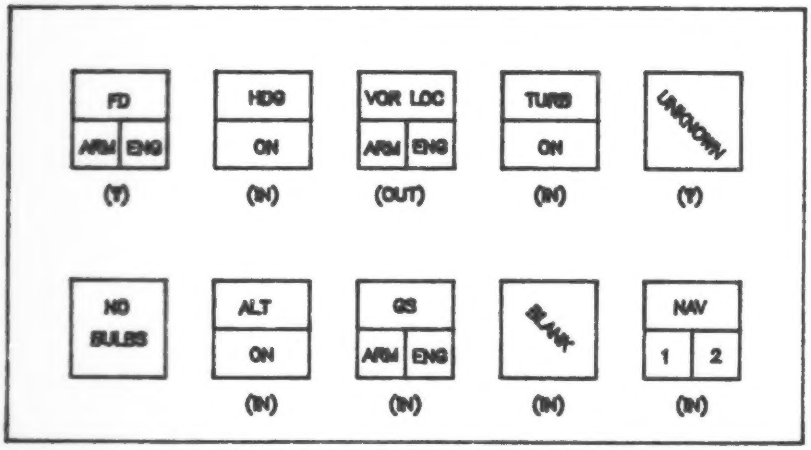
4.2 The "L HYD PRESS LO" contained bulbs with less damage than those above, but was also considered to be "on" at impact.

4.3 The condition of the "R HYD PRESS LO", "HYD LEVEL LO", "R ENG ICE FAIL", "L FUEL PRESS LO" and "R FUEL BOOST ON" annunciator panel bulbs as well as the remaining bulbs from the mode panel could not be absolutely determined, as the evidence was inconclusive.

4.4 The remaining indicator bulbs were all considered to be "off" at impact.

4.5 Because of time constraints, it is highly unlikely that bulbs exhibiting evidence of having been "on" could have been triggered during the impact sequence.

4.6 Appendix "A" contains a list of all the bulbs examined, along with analysis and conclusions.


FD
ARM
ENG
(?)
HDG
ON
(IN)
VOR LOC
ARM
ENG
(OUT)
TURB
ON
(IN)
UNKNOWN
(?)
NO
BULBS
ALT
ON
(IN)
GS
ARM
ENG
(IN)
BLANK
(IN)
NAV
1
2
(IN)

MODE PANEL

FIGURE 1: Schematic of Mode Panel.

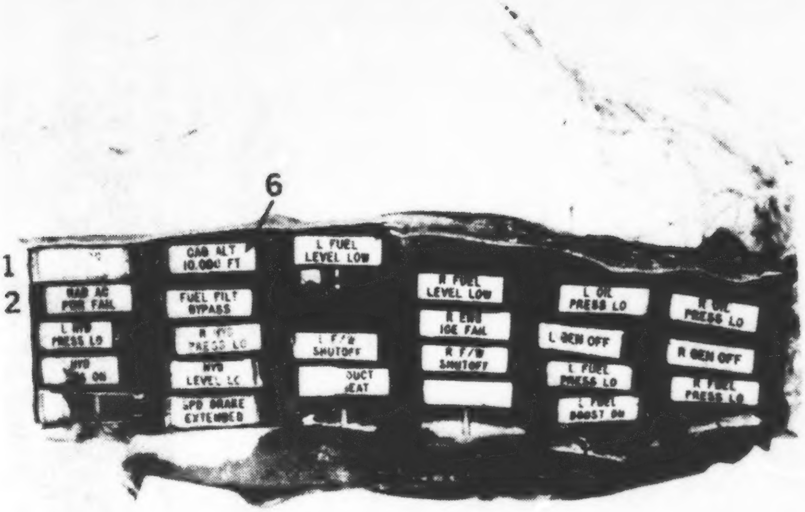

6
1
2
CAB ALT
10,000 FT
L FUEL
LEVEL LOW
FUEL FILT
BYPASS
R FUEL
LEVEL LOW
L OIL
PRESS LO
R OIL
PRESS LO
L HYD
PRESS LO
R HYD
PRESS LO
L F/W
SHUTOFF
R ENG
ICE FAIL
L GEN OFF
R GEN OFF
HYD
LEVEL LO
R F/W
SHUTOFF
L FUEL
PRESS LO
R FUEL
PRESS LO
DUCT
HEAT
SPD BRAKE
EXTENDED
L FUEL
BOOST ON

PHOTO 1 - ANNUNCIATOR PANEL AS-RECEIVED AT ASE. EACH INDICATOR PROVIDES A SPACE FOR TWO TYPE 327 SUB-MINIATURE LIGHT BULBS. NUMBER SCHEME FOR APPENDIX "A" IS SHOWN.

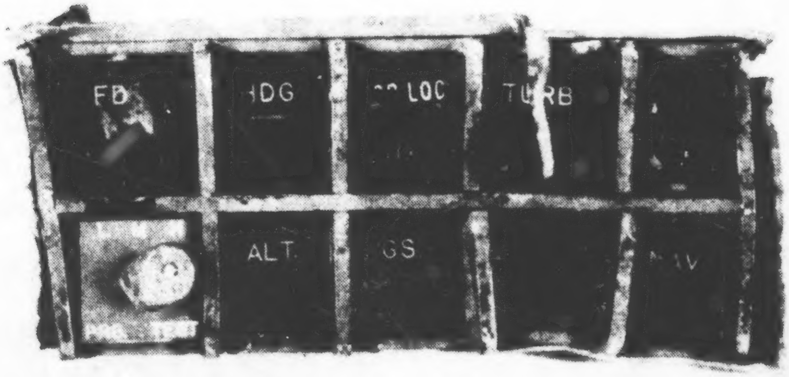

FD
HDG
LOC
TURB
ALT
GS
NAV
TEST

PHOTO 2 - MODE PANEL AS-RECEIVED AT ASE. EACH INDICATOR PROVIDES SPACE FOR FOUR BULBS.

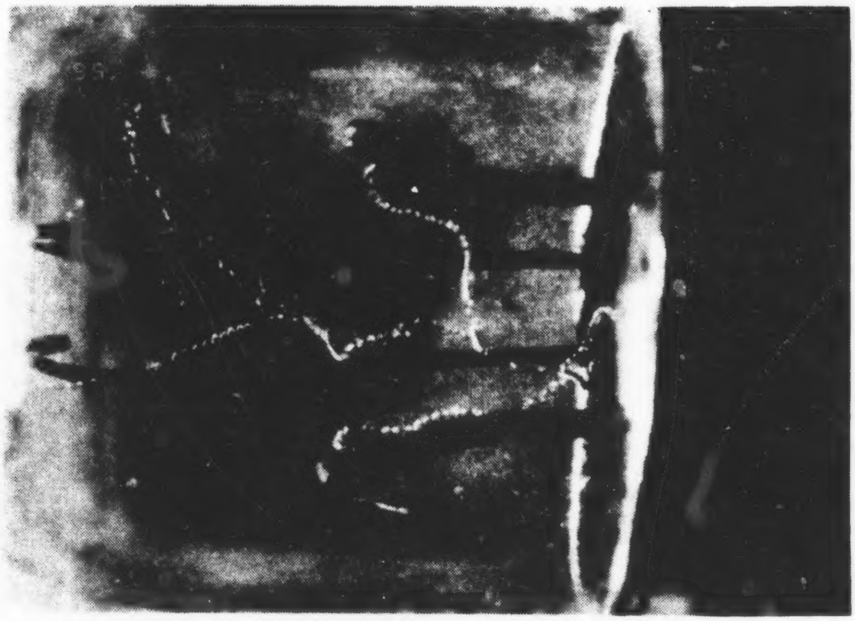


PHOTO 3 - TYPE 327 BULB FROM "DOOR NOT LOCKED" INDICATOR EXHIBITING SEVERE FILAMENT DEFORMATION AND UNCOILING.

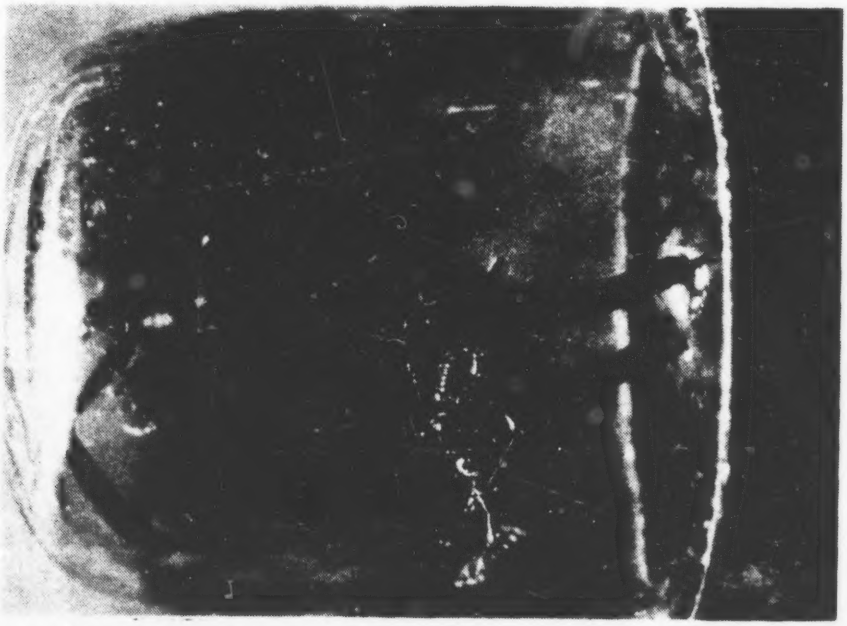


PHOTO 4 - TYPE 327 BULB FROM "DOOR NOT LOCKED" INDICATOR ALSO EXHIBITING SEVERE FILAMENT DEFORMATION AND UNCOILING.

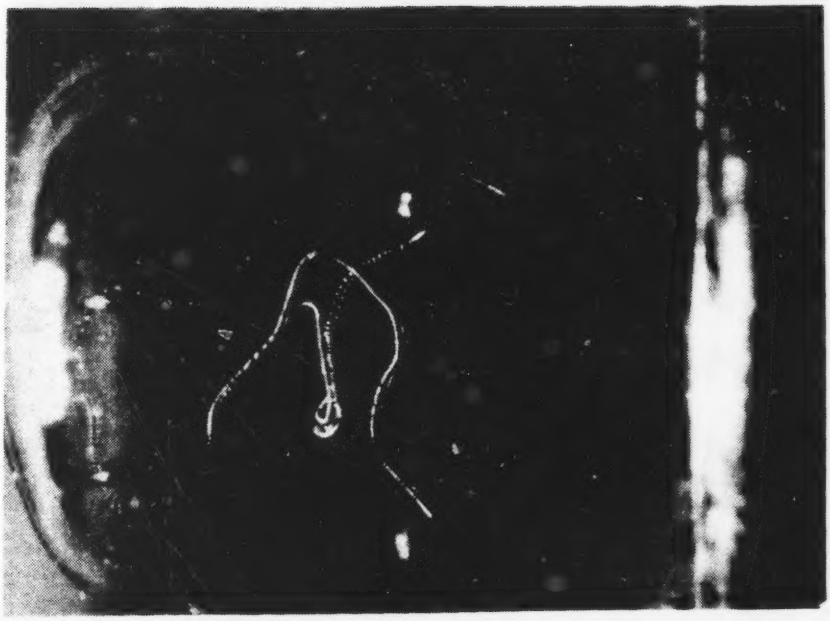


PHOTO 5 - TYPE 327 BULBS FROM "HYD PRESS ON" EXHIBITING SEVERE FILAMENT DEFORMATION AND UNCOILING.

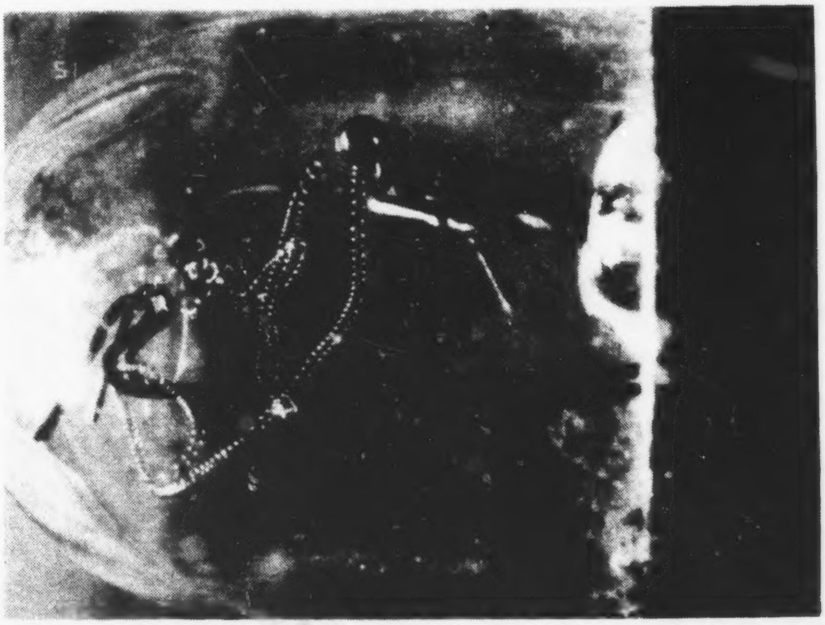


PHOTO 6 - TYPE 327 BULBS FROM "HYD PRESS ON" ALSO EXHIBITING SEVERE FILAMENT DEFORMATION AND UNCOILING.

PHOTO 7 - TYPE 327 BULB FROM "F/D AC PWR FAIL" EXHIBITING SEVERE FILAMENT DEFORMATION AND UNCOILING

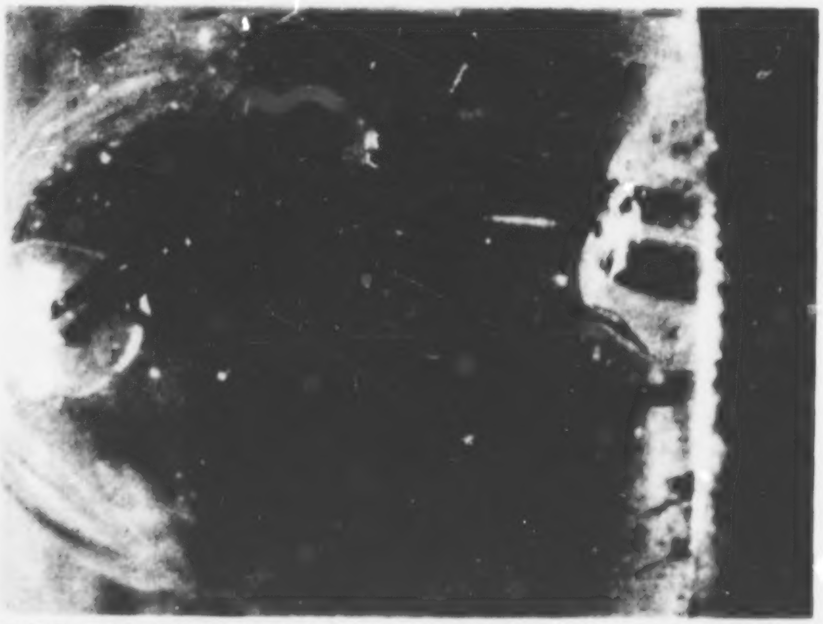


PHOTO 8 - TYPE 327 BULB FROM "F/D AC PWR FAIL" EXHIBITING SEVERAL FRACTURES OF THE FILAMENT WITH NO EVIDENCE OF DEFORMATION OR UNCOILING

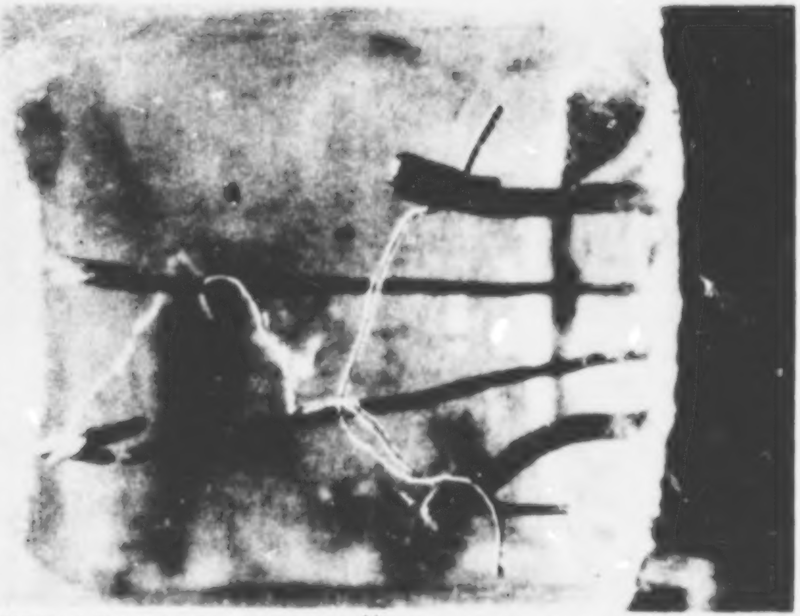


PHOTO 9 - TYPE 327 BULB FROM MASTER WARNING INDICATOR EXHIBITING FILAMENT DEFORMATION AND UNCOILING.

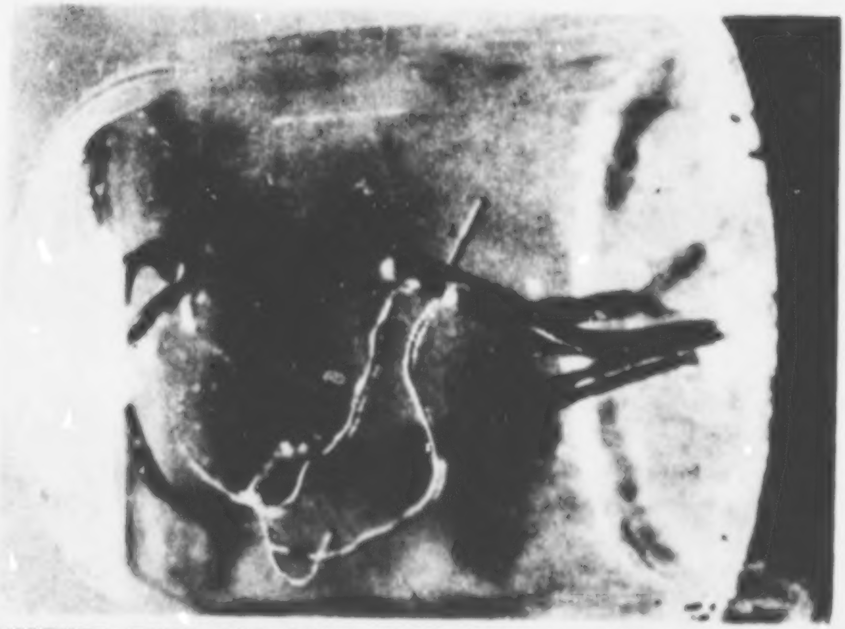


PHOTO 10 - ANOTHER TYPE 327 BULB FROM MASTER WARNING INDICATOR EXHIBITING FILAMENT DEFORMATION AND UNCOILING.

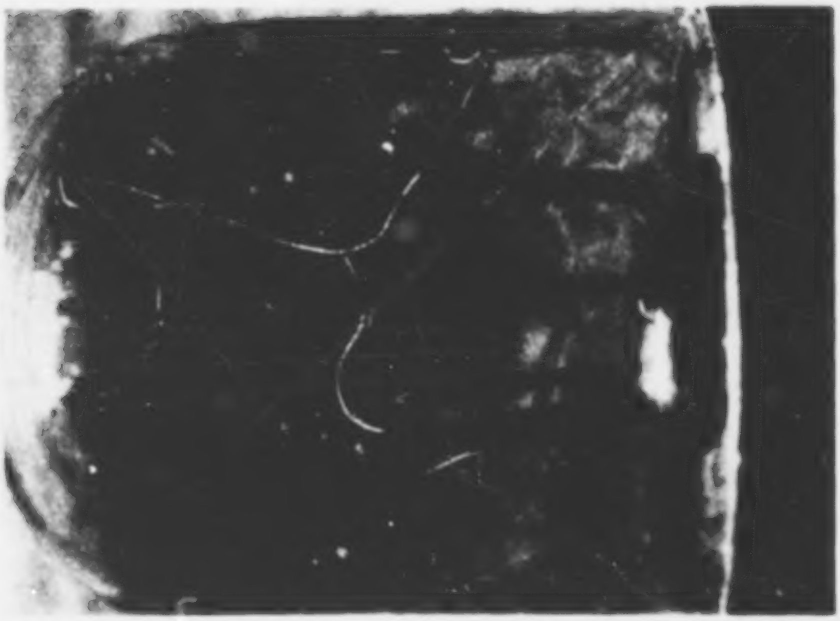


PHOTO 11 - TYPE 327 BULB FROM "L HYD PRESS LO" EXHIBITING MODERATE FILAMENT DEFORMATION AND SOME UNCOILING.

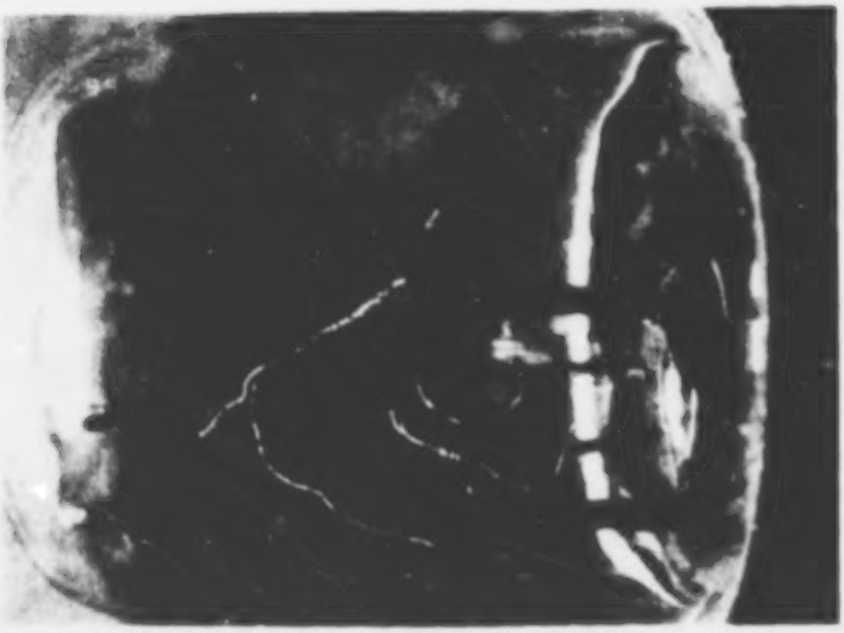


PHOTO 12 - REPRESENTATIVE BULB (TYPE 327) FROM THE "R ENG ICE FAIL" WITH SLIGHT FILAMENT DEFORMATION AND UNCOILING.

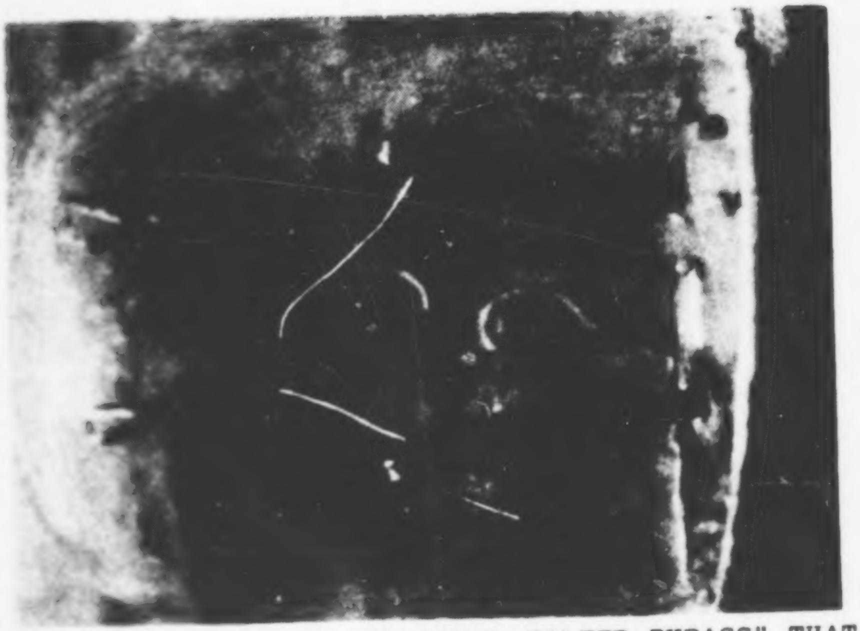


PHOTO 13 - TYPE 327 BULB FROM THE "FUEL FILTER BYPASS" THAT EXHIBITED SEVERAL FRACTURES BUT A TIGHLTY COILED, NON DEFORMED FILAMENT.

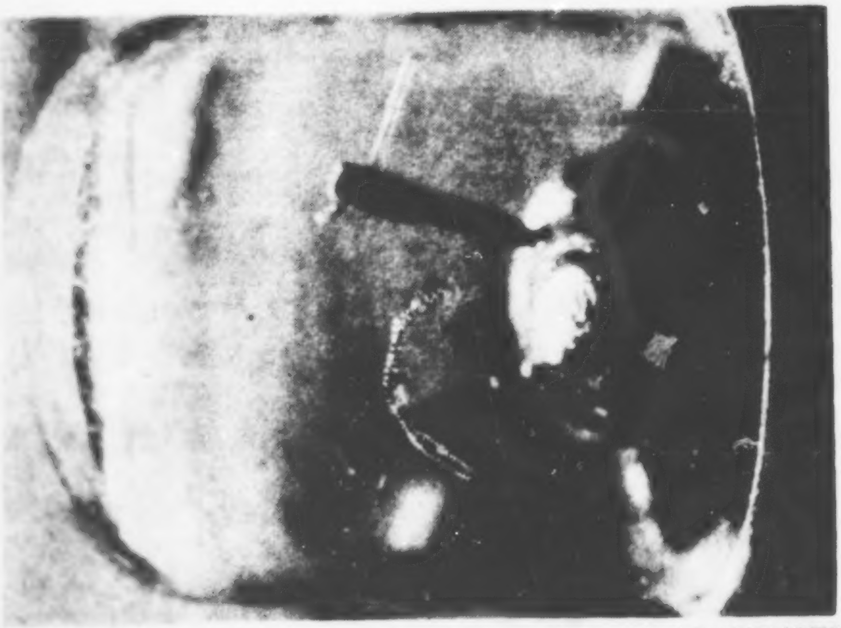


PHOTO 14 - TYPE 377 BULB FROM "ALT" MODE PANEL INDICATOR/SWITCH WITH SEGMENT OF FILAMENT FUSED TO THE GLASS ENVELOPE.

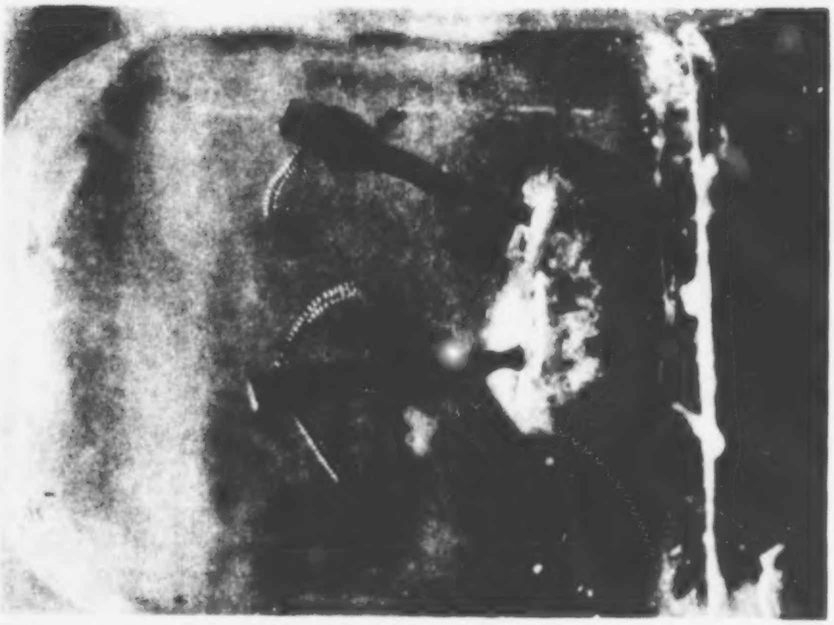


PHOTO 15 - TYPE 377 BULB FROM "HDG" INDICATOR SHOWING MODERATELY DEFORMED FILAMENT AND SMALL SEGMENT ADHERED TO THE TOP OF THE GLASS ENVVELOPE.

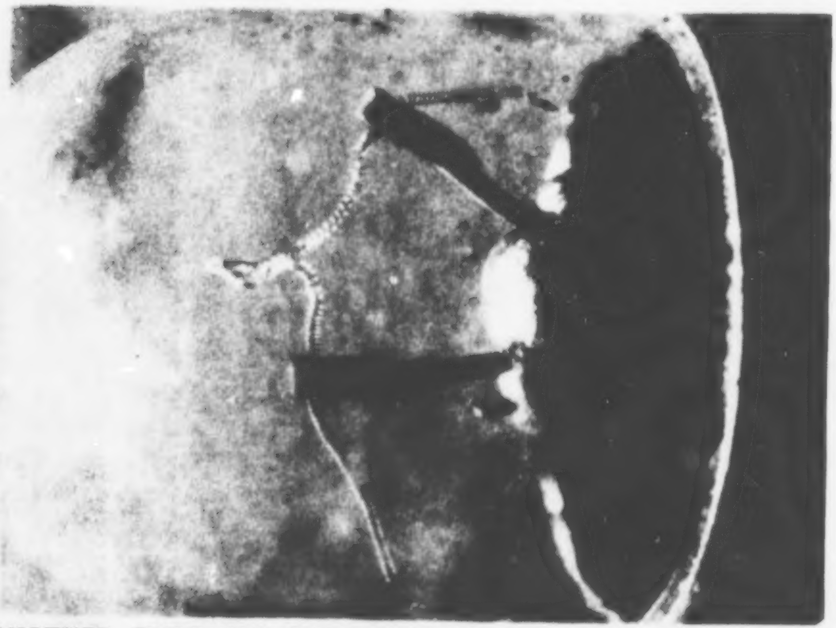


PHOTO 16 - ANOTHER TYPE 377 BULB FROM "HDG" INDICATOR SHOWING SEVERELY DEFORMED AND UNCOILED FILAMENT.

APPENDIX "A"

BULB	TYPE	GLASS ENVELOPE	STRETCH	FRACTURE	SEM	CONCLUSION
1a F/D A/C PWR FAIL 1b	CL-327 GE-327	Intact Intact	No Severe	Shattered None	Light aging -	OFF ON
2a RAD A/C PWR FAIL 2b	CL-327 GE-327	Intact Intact	No No	Shattered Several	Light aging Heavy aging	OFF OFF
3a L HYD PRESS LO 3b	GE-327 GE-327	Intact Intact	Moderate One	One segment One	Light aging Light aging	Probably On Probably On
4a HYD PRESS ON 4b	GE-327 CL-327	Intact Intact	Severe Severe	None None	- -	ON ON
5a UNKNOWN 5b (BLEED AIRGROUND)	CL-327 CL-327	Intact Intact	No No	Shattered Shattered	- -	OFF OFF
6a CAB ALT 10,000 FT 6b	CL-327 CL-327	Intact Intact	No No	Shattered Shattered	- -	OFF OFF
7a FUEL FILTER BYPASS 7b	GE-327 GE-327	Intact Intact	No No	Several One	- -	OFF OFF
8a R HYD PRESS LO 8b	GE-327 GE-327	Intact Intact	No Slight	Several None	- -	OFF Inconclusive
9a HYD LEVEL LO 9b	GE-327 CL-327	Intact Intact	Moderate Slight	Several Shattered	Light aging Light aging	Inconclusive inconclusive
10a SPD BREAK EXTENDED 10b	GE-327 GE-327	Intact Intact	Very Slight Very Slight	One Severed	- -	OFF OFF
11a L FUEL LEVEL LO 11b	GE-327 GE-327	Intact Intact	Very Slight No	One Fragment Shattered	- -	OFF OFF

APPENDIX A" (Cont'd)

BULB	TYPE	GLASS ENVELOPE	STRETCH	FRACTURE	SEM	CONCLUSION
12a Unknown	CL-327	Intact	No	Shattered	-	OFF
12b (L ENGINE FAIL)	GE-327	Intact	Very Slight	Several	-	OFF
13a LF/W SHUT OFF	GE-327	Intact	No	Several	-	OFF
13b	CL-327	Intact	No	Shattered	-	OFF
14a AIR DUCT	CL-327	Intact	No	One segment	-	OFF
14b O'HEAT	CL-327	Intact	No	Several	-	OFF
15a UNKNOWN	GE-327	Intact	Severe	None	Light Aging	ON
15b (DOOR NOT LOCKED)	GE-327	Intact	Severe	Several	Light Aging	ON
16a R FUEL LEVEL LO	GE-327	Intact	Slight	Several	-	OFF
16b	GE-327	Intact	No	Shattered	-	OFF
17a R ENG ICE FAIL	GE-327	Intact	Moderate	One	Light Aging	Inconclusive
17b	CL-327	Intact	Slight	Several	Light Aging	Inconclusive
18a RF/W	GE-327	Intact	No	Shattered	-	OFF
18b SHUTOFF	GE-327	Intact	No	Several	-	OFF
19a UNKNOWN	CL-327	Intact	No	Shattered	-	OFF
19b (EMER PRESSON)	GE-327	Intact	Slight	Several	-	OFF
20a No bulbs						
20b						
21a L OIL PRESS LO	GE-327	Intact	Very Slight	Several	-	OFF
21b	GE-327	Intact	Very Slight	Several	-	OFF
22a L GEN OFF	GE-327	Intact	Very Slight	Several	Mod. Aging	OFF
22b	GE-327	Intact	Very Slight	Several	Mod. Aging	OFF

APPENDIX "A" (Cont'd)

BULB	TYPE	GLASS ENVELOPE	STRETCH	FRACTURE	SEM	CONCLUSION
23a L FUEL PRESS LO	GE-327	Intact	No	One fragment	Heavy age	OFF
23b	GE-327	Intact	Moderate	One	Heavy age	INCONCLUSIVE
24a L FUEL BOOST ON	GE-327	Intact	Very Slight	Several	Light aging	OFF
24b	GE-327	Intact	Very Slight	None		OFF
25a UNKNOWN	CL-327	Intact	No	Shattered	-	OFF
25b (BATTERY HEAT)	No Bulb					
26a R OIL PRESS	GE-327	Intact	No	Shattered	-	OFF
26b	GE-327	Intact	Very Slight	Shattered	-	OFF
27a R GEN OFF	GE-327	Intact	No	Several	Light aging	OFF
27b	GE-327	Intact	Very Slight	Several	Light aging	OFF
28a R FUEL PRESS LO	GE-327	Intact	No	Several	Hevay aging	OFF
28b	GE-327	Intact	Moderate	Several	Heavy aging	OFF
29a UNKNOWN	GE-327	Intact	No	Several	Light aging	Off
29b (R FUEL BOOST ON)	GE-327	Intact	Moderate	Several	Light aging	Inconclusive
30a FD	GE-328	Intact	Slight	One	Light aging	Inconclusive
30b FD	GE-328	Intact	Moderate	None	Light aging	Inconclusive
30c ARM	GE-328	Intact	Slight	One	Light aging	Inconclusive
30d ENG	GM-328	Intact	Slight	One	Light aging	Inconclusive
31a HDG	CM-377	Intact	Severe	One	-	ON*
31b HDG	CM-377	Intact	Severe	None	-	ON
31c ON	CM-377	Intact	Severe	One	-	Inconclusive
31d ON	CM-377	Intact	Slight	One	-	Inconclusive

* (Segments fused to glass)

APPENDIX "A" (Cont'd)

BULB	TYPE	GLASS ENVELOPE	STRETCH	FRACTURE	SEM	CONCLUSION
32a VOR LOC	CM-377	Intact	No	One	-	Inconclusive
32b VOR LOC	CM-377	Intact	Slight	None		Inconclusive
32c ARM	CM-377	Intact	Slight	None		Inconclusive
32d ENG	CM-377	Intact	Slight	One	-	Inconclusive
33a TURB	CM-377	Intact	No	Several	Light aging	Inconclusive
33b TURB	CM-377	Intact	Slight	One	Light aging	Inconclusive
33c ON	CM-377	Intact	Slight	One	Light aging	Inconclusive
33d ON	CM-377	Broken	Slight	Several	Light aging	Inconclusive
34a UNKNOWN F	CM-377	Intact	Slight	Several	Light aging	ON
34b (BACKCOURSE)	CM-377	Intact	Slight	Several	Light aging	ON*
34c	CM-377	Intact	Slight	Several	Light aging	Inconclusive
34d	CM-377	Intact	Slight	Several	Light aging	Inconclusive
35a ALT	CM-377	Intact	Slight	Several	-	ON*
35b ALT	CM-377	Intact	Slight	Several	-	ON*
35c ON	CM-377	Intact	Slight	Several	-	ON*
35d ON	CM-377	Intact	Slight	Several	-	ON*
36a GS	CM-377	Intact	Moderate	One	Light aging	Inconclusive
36b GS	CM-377	Intact	No	Several	Light aging	Inconclusive
36c ARM	CM 377	Intact	No	Several	Light aging	Inconclusive
36d ENG	CM-377	Intact	Slight	One	Light aging	Inconclusive
37a NAV	CM-377	Intact	Moderate	None	Light aging	Inconclusive
37b NAV	CM-377	Intact	Moderate	None	Light aging	Inconclusive
37c 1	CM-377	Intact	Slight	Several	Light aging	Inconclusive
37d 2	CM-377	Intact	Slight	Several	Light aging	Inconclusive

* (Segments fused to glass)

APPENDIX "A" (Cont'd)

BULB	TYPE	GLASS ENVELOPE	STRETCH	FRACTURE	SEM	CONCLUSION
38a MASTER WARNING	GE-327	Intact	One	Moderate	Light aging	ON
38b	GE-327	Intact	One	Moderate	Light aging	ON
38c	GE-327	Intact	One	Moderate	-	ON
38d	GE-327	Broken	-		-	